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DETERMINATION OF EFFICIENT METHODS OF LIFT BY COMPARING
TRAINED AND UNTRAINED MALE AND FEMALE LIFTERS

Richard H. Shannon

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NAVAL BIODYNAMICS LABORATORY
New Orleans, Louisiana

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DETERMINATION OF EFFICIENT METHODS OF LIFT BY COMPARING

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Richard H. /Shannon

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The primary objective of this investigation was to analyze the effects of sex and training variables during non-repetitive, short duration lifts in the sagittal plane. A sample of sixteen subjects (eight men and eight women) were used in the experiment. Selection of these subjects was based on the need to control for size, weight, age and experience. One-half of each sex sub-sample was part of a lifting training program, while the other half was used as a control group. The effects of body movements by these subjects in the height ranges from the floor to the knuckle and the knuckle to the shoulder were

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ascertained with 10, 25, 40 pound weight loads. Data were collected using
electromyograms to determine muscular strain, stroboscopic photography to
calculate differences in displacement - time vectors, and the force platform
to specify force changes at the feet. The data were analyzed using various
statistical techniques - factor analysis, regression analysis, analysis of
variance, t-test and non-parametric statistics. The results of this effort
were a five factor biomechanical model, regression equations predicting
inertial forces at the hands, and significant differences between the un-
trained and trained conditions, and males and females. The overriding
conclusion is that manual handling training programs are necessary in the
work environment if women are expected to lift loads of approximately 40
pounds.

Accession

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TEXAS TECH UNIVERSITY
The Graduate School
LUBBOCK, TEXAS

ABSTRACT OF DISSERTATION

for the Degree of

DOCTOR OF PHILOSOPHY

Author's Full Name: RICHARD H. SHANNON

Title of Dissertation: Determination of Efficient Methods of Lift
by Comparing Trained and Untrained Male
and Female Lifters

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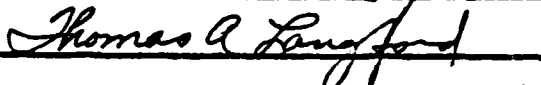
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The primary objective of this investigation was to analyze the
effects of sex and training variables during non-repetitive, short
duration lifts in the sagittal plane. This type of lift is defined as
one which is performed occasionally during the workday and lasts no
more than five seconds. The underlying assumption is that men and women
who undergo a training program involving the lifting of materials will
come closer to an optimized, efficient lifting technique than those who
are untrained.

This investigation involved a sample of sixteen subjects - eight
women and eight men, all Texas Tech students. Selection of these

1

subjects was based on the need to control for size, weight, age and experience. One-half of each sex sub-sample was part of a lifting training program, while the other half was used as a control group. The effects of body movements by these subjects in the height ranges from the floor to the knuckle and the knuckle to the shoulder were ascertained with 10, 25, 40 pound weight loads. Data were collected using electromyograms to determine muscular strain, stroboscopic photography to calculate differences in displacement - time vectors, and the force platform to specify force changes at the feet. The data were analyzed using various statistical techniques - factor analysis, regression analysis, analysis of variance, t-test and non-parametric statistics. A multivariate approach was used because of the multi-modality data collected during the experiment.

The significant conclusions of this investigation are as follows:

1. A five-factor biomechanical model utilizing factor analysis was developed for non-repetitive, short duration tasks in the sagittal plane during floor-knuckle and knuckle-shoulder lifts.

2. Regression equations demonstrated that there were significant relationships between inertial forces at the hands (film) and forces at the feet (force platform). The major contributor in these equations was the force in the transverse plane.

3. The major movement predictors in another set of regression equations which analyzed inertial forces at the hands were accelerations at the arms and lower arms, respectively, for the floor-knuckle and knuckle-shoulder lifts.

4. Males had higher accelerations and decelerations than females, respectively, during he 0 - .25 second and .51 - .75 second time frames in the y axis for the floor-knuckle lift.

5. In the knuckle-shoulder lift, men relied more on back and arm muscles, while women used more leg and back motion to supplement strength differences.

6. Trained individuals demonstrated more efficient and coordinated lifts in the y axis of both lifts by having similar patterns of acceleration with, but significantly higher deceleration patterns from, the untrained condition. This would appear to indicate that trained people accomplished the same task with less effort.

7. Male movements approximated the trained condition while female lifts were similar to the untrained sample.

8. The weight variable had greater influence during the knuckle-shoulder lift with most of the weight comparisons between forces at the feet and hands being significant. On the other hand, the effect of object weight in the floor-knuckle regime was small. The significant differences between forces were mainly observed between the 10 and 40 pound loads.

9. Most of the variance in the y axis for the sex/weight interaction can be attributed to untrained females lifting 40 pounds in the knuckle-shoulder lift. Acceleration pattern differences were not noted between weight conditions and all males or trained females. This statement would indicate that training programs are necessary in the industrial environment if women are expected to lift loads of approximately 40 pounds.

DETERMINATION OF EFFICIENT METHODS OF LIFT

BY COMPARING TRAINED AND UNTRAINED

MALE AND FEMALE LIFTERS

by

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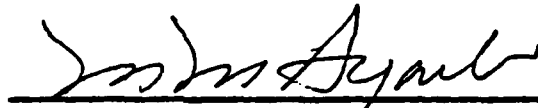
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CHAPTER I

INTRODUCTION

In the industrial environment, one of the tasks performed by man
is the manual handling of materials. Since approximately one-quarter
of all compensable work injuries occur during the performance of this
task (Accident Facts, 1971), a need exists to study this problem. This
issue is further emphasized by the number of women who are now entering
the work force and performing tasks which were previously assigned to
men.

Most manual handling injuries occur while an individual is lifting
rather than pushing, pulling or carrying a load (Shannon, 1978). A
state of lifting exists whenever a moment, the product of force and
distance, acts upon the body. This situation, even with light loads,
causes some work stress and physiological work strain. This statement
becomes more significant when one considers that the heaviest material
handled by man may be his own body (Tichauer, 1973).

In order to gain insight into the various aspects of the problems
associated with manual lifting, research should be directed toward a
better understanding of the strains and stresses resulting from this
type of task. These efforts would eventually result in better selection
measures, adequate training programs, increased worker efficiency and a
reduction of bodily injury. The need for such studies was mentioned in
a recent review (Herrin, Chaffin, Mach, 1974) of the manual materials
handling literature. These authors recommended that future investiga-
tions emphasize the following objectives:

1. More comprehensive biomechanical models should be constructed
and used to predict complex mechanical stresses.

2. Better techniques should be developed for evaluating kinesio-
logical and postural changes.

3. Because the present rules pertaining to lifting postures are
overly simplistic, future studies should lead to more representative
models of the body as well as critical validation of these models.

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4. The fundamental physical characteristics and hazard potentials within and between the sexes should be studied.

5. Future experiments with training should use a comparison or control group which did not undergo any training during the study.

Purpose and Scope

The primary objective of this investigation was to analyze the effects of sex and training variables during non-repetitive, short duration lifts in the sagittal plane. This type of lift is defined as one which is performed occasionally during the workday and lasts no more than five seconds (El-Bassoussi, 1974). The underlying assumption is that men and women who undergo a training program involving the lifting of materials will come closer to an optimized, efficient lifting technique than those who are untrained.

This investigation involved a sample of sixteen subjects - eight women and eight men, all Texas Tech students. Selection of these subjects was based on the need to control for size, weight, age and experience. One-half of each sex sub-sample was part of a lifting training program, while the other half were used as a control group. The effects of body movements by these subjects in the height ranges from the floor to the knuckle and the knuckle to shoulder were ascertained with 10, 25, 40 pound weight loads. Data were collected using electromyograms to determine muscular strain, stroboscopic photography to calculate differences in displacement-time vectors, and the force platform to specify force changes at the feet. These data were analyzed using various statistical techniques - factor analysis, regression analysis, analysis of variance, t-tests and nonparametric statistics. A multivariate approach was used because of the multimodality data collected during the experiment. Analyses of the data in this experiment for each lifting regime will result in:

(1) the identification of the dependent variables into clusters of bodily movement.

(2) the development of a lifting model to predict inertial force or stress at the hands.

(3) the determination of differences between trained and untrained lifters.

(4) the determination of differences between male and female lifters.

(5) recommendations involving the lifting of manual materials based on the effects of sex and training.

CHAPTER II
REVIEW OF LITERATURE

Biomechanics

Biomechanics is the discipline which investigates the structure
and function of living systems by utilizing the knowledge and methods of
mechanics as well as the biological laws of life. The methodology
involved in this field requires a multidisciplinary approach in order
to understand man's interaction with his external environment. Research
incorporates the findings from the following scientific fields:

physics - assessment of the mechanical components of motion

physiology - identification of the functional parameters of motion

anatomy - analysis of bodily structure

psychology - consideration of the mental processes in control and
perception of movement.

This synthesis of the biological and mechanical utilizes various
approaches such as cinematography, stroboscopy, goniography, electro-
physiology, and velocity/acceleration and force measurements. The major
areas which can benefit from biomechanical research are sport and
physical education, orthopedics and rehabilitation, music and dancing,
human engineering and ergonomics (Wartenweiler 1973, 1974).

The following conceptual classification of motor manifestation
(Wartenweiler, 1968) can be used as an aid to better understand the
multifacited nature of biomechanics:

1. Content of Motor Acts

    a) purposive movements, such as hammering a nail.

    b) expressive movements, such as laughing.

2. Magnitude of Movements

    a) mass movements involving major parts of the body.

    b) small movements, such as finger dexterity.

3. Nature and Degree of Resistance

    a) external resistance movements, such as pushing a cart.

    b) ballistic movements, such as running.

c) patterned resistance movements of antagonistic muscles, such as demonstrated in ballet dancing.

4. Design of Motion

a) elementary movements of single body components, such as a swinging arm with the body at rest.

b) combined movements, such as the displacement of two or more segments to achieve a single purpose,

- co-movements (lunge in fencing)
- counter-movements (arm swinging and walking)
- phasic displacement movements (throwing).

c) joint movements, such as displacement of two or more segments with each having a separate purpose (arm and leg movement in swimming).

d) superimposed movements, such as movement having no other purpose than symbolism (Hindu dancing).

5. Optimal Movement Characteristics

a) rhythm - continuity of force development, acceleration and deceleration, approaching repetitive sinusoidal prototype.

b) coordination - development of force release in keeping with objective of total motor performance (transfer of impulse).

c) relaxed intervals - antagonistic muscles acting alternatively, without extended overlap.

d) anticipatory initiation of motor act - movements aimed at maximal performance initiated by counter displacements of body components resulting in:

- optimal positioning of joints
- lengthening of range of effective action
- facilitation of force release.

6. Movement Variations

a) motor personality - classification of motion based on somatic individual differences.

b) skill - influence of skill and training on bodily movement.

c) pathological interference - deviations of optimal motor patterns due to disease and injury.

Using this conceptual outline, movement in the present study can be classified as:

1. "purposive" due to lifting of manual loads with a simulated objective.

2. "mass" involving total motion of the body.

3. "external" resistance because of the load lifted.

4. "combined" consisting of the displacement of bodily segments in order to lift an external load.

5. "rhythmic" because of smooth curvilinear patterns of acceleration and deceleration.

6. "coordinated" due to the transfer of forces between the various bodily segments.

7. "anticipatory" involving coordinated and rhythmic movements through individual planning.

8. "skilled" due to the analysis of training effects.

9. "motor personality" because of the goal to compare male and female movement due to inherent somatic differences.

In addition, the findings from this research will have application in the fields of human engineering and ergonomics because of its concern for optimal working conditions and personnel injury within the industrial environment.

As an aid in the analysis of motor behavior during the lifting of materials, biomechanical models have been used to study the effects of reactive forces and torques on the joints and links of the human body. In order to apply the mechanical laws of Newton to this type of research, knowledge of an individual's segment lengths, center of gravities and weight should be known. The first significant work on segmental centers was performed by Braune and Fischer (1963) through their dissections of three cadavers. In 1955, Dempster extended this work by analyzing eight cadavers which resulted in better estimates of bodily dimensions. This research was further expanded by Clauser (1969) who used the water displacement method on living subjects to determine segment weights as percentages of total body weight.

Plagenhoef (1971) applied Dempster's mass distribution data in the analysis of complex body motions during various sports activities. He used free-body diagrams to calculate translational accelerations, segment forces and joint moments of force. With this information, he analyzed specific motion as well as quality of performance. His data output listed the contribution of body segments due to maximum absolute decelerations, relative motion of each link and extent of muscular action.

A biomechanical model for the upper extremity was developed by Ayoub (1971) in order to predict paths of motion. An optimizing principle was used which sought to minimize the performance criterion under specific physical and stress constraints. An experiment was conducted to test the accuracy of the prediction model. Ten subjects were observed by use of photographic records under three levels each of work surface, height and motion distance. The results indicated that predicted and observed motion were highly related, and that total power required for the motion was the most suitable mechanical criterion.

El-Bassoussi (1974) developed a biomechanical model to calculate physical stress on the musculo-skeletal system. In this study, two types of lift (leg and back), three load levels (10, 20, 30 pounds) and three box sizes were used. Tichauer's (1971) concept of biomechanical lifting equivalent (BLE) was used in the experiment by considering weight lifted and moment arm (box size) as independent variables. These nine combinations of weight/bulk ratios ranged in size from 140 to 600 pound inches. The dependent variables were the maximum compressive and shearing forces on certain vertebrae (upper S1, lower L5, upper L5, lower L4). The results indicated that the back lift produced greater compressive forces on the spine than the leg lift, and that shearing forces never exceeded 100 kg for both lifts.

Lifting Injury and Prevention

The handling of manual materials is one of the necessary tasks performed by people in the industrial environment. The risk of injury, especially to the lower back, during load handling is effected by

numerous variables. These variables were outlined in a recent review
(Herrin, Chaffin, Mach, 1974) of the manual materials handling litera-
ture. A classification schema was used in this survey in order to
categorize 488 research reports into four overall groups - worker,
material/container, task and work practices. This breakdown is as
follows:

1. Worker variables consisting of -

a) physical measures involving age, sex, and anthropometry.

b) sensory measures involving visual, tactual, kinesthetic,
and vestibular.

c) motor measures involving strength, endurance, and
coordination.

d) personality measures involving high risk acceptance and
high perceived economic need.

e) experience measures involving work experience and training.

f) health measures involving medical status, drug usage, and
physical conditioning.

2. Material/container variables consisting of -

a) load measures involving amount of weight and moments of
inertia.

b) dimension measures involving container size and shape.

c) distribution measures involving center of gravity of load/
worker and its stability.

d) coupling measures involving handle size, texture, shape,
and location.

3. Task variables consisting of -

a) spatial measures involving distance moved, obstacles
encountered, and direction of path.

b) time measures involving frequency, duration, and pace.

c) environmental measures involving temperature, humidity,
noise, and vibration.

4. Work practice variables consisting of -

a) individual operating practices involving lifting/posture
techniques.

b) organizational operating practices involving medical/safety functions, job teamwork, and amount of supervision.

c) administrative operating practices involving compensation, work shifts, job rotation, and safety training.

Taxonomic classification such as this outline is a very important tool. Without a unifying system, Chambers (1969) believes it would be exceedingly difficult to achieve generalization of research results, communication between research and applied workers, application of research results to applied problems, and utilization of data acquired from one applied situation to another. An example of this schema's utility, the present investigation can be labeled as studying:

1. worker variables of sex, coordination, kinesthetic sense and training.

2. material/container variable of weight.

3. task variable of lift type.

4. work practice variables of lifting/posture technique and safety training.

This outline of the literature helps a researcher to determine the size and scope of the lifting problem as well as to isolate specific areas for future investigations. One way of utilizing this model would be to analyze company insurance and medical reports involving injury from material handling operations. These critical incidents can give some insight into the frequency, causes and seriousness of the problem. A content analysis can be performed on these qualitative records resulting in the extraction of quantitative information (Flanagan, 1954). There are certain limitations to this technique, however, which are:

1. All mishaps are not reported.

2. The reports, although based on expert opinion, are still subjective and open to error.

3. The reports are too concise and not sufficiently detailed.

4. The content analysis of the reports depends upon the subjective evaluation of an investigator.

Although these field surveys have limitations, they can be considered very useful in giving the researcher an historical perspective (Shannon, 1978).

The following paragraphs will review some of the literature pertaining to this type of analysis.

Troup (1965) indicated that approximately 12% of industrial injuries are related to back problems caused by handling materials. Magora and Traustein (1969) listed the percentages of total injury by occupation for back pain as varying from 6.4% for policemen to 21.6% for heavy industry with an average of 13.2% for the total listed occupations. Shannon (1978) analyzed 484 strain/sprain/overexertion injuries resulting from load handling by naval civilian government workers during a one year period (July 1976 - June 1977). Content analysis was performed isolating quantitative information based on age, bodily injury, days absent, month of year, occupation, type of handling, weight handled, and human error causality. This information is presented in Tables 1, 2, 3, with statistical comparisons tested by a t-test of percentage differences (Garret, 1966). In some cases the numbers are higher (injury) or lower (causality, age) than 484 indicating that more than one area of the body was overexerted during an incident or that some of the reports did not contain age or causality data. Whichever the case, the data are compared using the number of data points per descriptive section.

The t-test of percentage differences was used in this study (Shannon, 1978) to determine whether there were a proportionately higher number of injuries per qualitative category by comparing (a) males and females and (b) total cases to a standard percentile representing chance. Male and female comparisons were performed using the total number of cases within a specific category. The second test relied upon using reference values to signify chance. These values were computed in all cases except two (occupation and causality) by dividing 100% by the number of specific categories within a section. For example, there are five variables listed under bodily injury (Table 1) which resulted in a reference value of 20%. The two categories that did not fit the mold for estimating reference values were occupation (Table 1) and causality (Table 2). The standard percentage for occupation was 30% ($\frac{100\% - 10\%}{5 - 2}$, clerical and transportation were estimated to be 10% and subtracted from the total), while

TABLE 1
WORKER DESCRIPTIVE BREAKDOWN OF 484 INJURIES
WHILE HANDLING MANUAL MATERIALS
(Source: Shannon, 1978)

VARIABLES	MALES(p)	FEMALES(p)	% OF * TOTALS(p)
AGE:			
17 - 29	117	27	31.6(.01)
30 - 39	94	24	25.9
40 - 49	83	18	22.1
Over 50	83	10	20.4
	377	79	100.0
BODILY INJURY:			
Back	317(.01)	58	72.1(.01)
Pelvis/Abdomen	26	8	6.5
Thorax/Shoulder/Neck	43	18(.05)	11.8
Arm/Hand	17	7	4.6
Leg/Foot	22	4	5.0
Total	425	95	100.0
DAYS ABSENT:			
1 - 4 (minor injury)	178	57(.01)	48.6
Over 5 (major injury)	223(.01)	26	51.4
Total	401	83	100.0
MONTHS OF YEAR:			
JAN - MAR	90	26	24.0
APR - JUN	120(.01)	13	27.5
JUL - SEP	102	27	25.6
OCT - DEC	89	17	21.9
Total	401	83	100.0
OCCUPATION:			
Sales/Service	60	48(.01)	22.3
Storage/Warehouse	115	26	29.1(NS)
Mechanical/Technical	177(.01)	5	37.6(.01)
Clerical/Professional	20	3	4.8
Transportation/Equipment Operator	29(.05)	1	6.2
	401	83	100.0

* (standard percentages were 30% for occupation, the remaining sections
used 100%/# of variables)

TABLE 2

TASK DESCRIPTIVE BREAKDOWN OF 484 INJURIES

WHILE HANDLING MANUAL MATERIALS

VARIABLES	MALES(p)	FEMALES(p)	% OF * TOTALS(p)
TYPE OF HANDLING:			
Lift	303	58	74.6(.01)
Push/Pull	47	15	12.8
Carry	51	10	12.6
Total	401	83	100.0
WEIGHT:			
Light (1 - 14 lbs.)	14	13(.01)	5.6
Medium (15 - 35 lbs.)	83	43(.01)	26.0
Heavy (36 - 59 lbs.)	202(.01)	22	46.3(.01)
Very Heavy (over 60 lbs.)	102(.01)	5	22.1
Total	401	83	100.0
HUMAN ERROR CAUSALITY:			
Load too heavy	79	10	48.9
Poor load handling technique	60	17(.05)	42.3
Failure to recognize safety hazard	16	0	8.8
Total	155	27	100.0

* (standard percentages were 45% for causality, the remaining sections
used 100%/# of variables)

Source: Shannon, 1978

TABLE 3   13

HUMAN ERROR CAUSES OF 484 INJURIES WHILE HANDLING MANUAL MATERIALS
(Source: Shannon, 1978)

		M	F	Major* Injury
A.	Load too heavy: (Total)	(79)	(10)	(56)
	1. did not check loads resistance prior to handling	18	4	12
	2. did not use handling equipment	19	1	13
	3. did not seek assistance from other personnel	25	2	17
	4. should not have exceeded bodily limitations due to prior injury	17	3	14
B.	Poor load handling technique: (Total)	(60)	(17)	(38)
	1. twisted body while handling load	18	6	10
	2. body/feet not properly balanced	9	1	5
	3. load not properly gripped	8	0	5
	4. knees not bent	3	4	4
	5. back not straight	2	0	0
	6. poorly trained in proper methods (supervisory)	6	4	2
	7. did not use two but one hand lift causing unbalanced situation	2	0	2
	8. did not coordinate two person lift causing unbalanced weight distribution	3	0	2
	9. lifted load too far from body	7	2	6
	10. did not properly position load at truck's edge prior to lift causing inadvertent falling from truck	2	0	2
C.	Failure to recognize safety hazard: (Total)	(16)	(0)	(11)
	1. carrier not secured causing carrier movement during lift	3	0	2
	2. material on carrier not secured, strain caused by attempted prevention of load falling	5	0	4
	3. poor design of equipment (supervisory)	3	0	3
	4. poor maintenance of equipment (supervisory)	4	0	1
	5. handling equipment not available (supervisory)	1	0	1
TOTAL:		155	27	105

* (represents 5 or more days absence)

causality used 45% ($\frac{100\% - 10\%}{3 - 1}$, safety hazard recognition was estimated to be 10% and subtracted from the total). The t-tests for male/female comparisons were two-tailed, while total/reference determinations were one-tailed because only values greater than the standard were of interest.

A similar study pertaining to a California work sample (Leavitt, Johnson and Beyer, 1971) indicated that 60% of the injuries in the study were due to strain and overexertion. Of these, approximately 80% were back and spine strains. The highest rate of occurrence by age was 40 - 49 (30%), 20 - 29 (20%) and 50 - 59 (20%). Adams (1973) cited information from Accident Facts (1971) that 22.6% of all compensable work injuries and 13.9% of all fatal or permanent injuries during 1971 were related to manual material handling. The author concluded that handling injuries are among the most frequent and costly types of compensable work injuries. Since Adams believed that standards could not be determined that would protect all workers from possible injury, he stated that the best approach would be to focus upon the frequent and serious problem of back overexertion.

To summarize, the major flaw in this type of work is that the analysis is based on the subjective categorization by the reviewer. Significance of a category is quite dependent upon these judgments. The reader, therefore, should consider statistics in this type of research to be used more for descriptive purposes and rough comparisons of data than that of stringent discriminant analyses.

After studying industrial selection and training programs, Snook (1978) believed that the most cost-effective approach to the problem of back injuries was the determination and use of safe weight lifting values. Presently, the National Institute for Occupational Safety and Health are attempting to establish criteria and standards for manual material handling. There is a need for these regulations because of the diversity existing among state codes, which only controlled one of the pertinent variables, that of object weight (International Labor Organization, 1966). Worker characteristics, bulk-weight ratios, lifting heights and frequencies of lift are not considered (Tichauer, 1971; Knipfer, 1973).

Various researchers have attempted to study these variables. The
work of McDaniel (1972), Dryden (1973), and Knipfer (1973), using samples
of males and females, obtained maximum acceptable weights by population
percentiles for the floor-knuckle, knuckle-shoulder and shoulder-extended
reach lifts. In addition, equations predicting these workload values
were formulated based on a subject's anthropometric and strength data.
Other studies (Snook et al, 1967, 1969, 1974; Snook, 1978) have looked
at the same range of lifts for male and female subjects. These seven
studies used a psychophysical methodology which allowed the subjects to
adjust their workload to a comfortable weight level while conducting
repetitive lifts. The purpose was to determine an acceptable load value
which would permit maximum effort with minimum strain.

Another investigation (Ayoub, 1978) analyzed six lift ranges, four
frequency rates and three box sizes over various age, sex and weight
categories of industrial workers. This research also used a psycho-
physical methodology. Table 4 lists the acceptable weight values for
males and females over the six ranges of lift as determined from this
study.

Other experimenters have choosen to study lifting techniques as a
means of alleviating injury. Grieve (1974) used a force platform and
photographic methodology to assess two subjects lifting three loads
(4, 14, 29 kg) during two types of lifts (crouch, stoop). The major
differences between both types of lift were in the force patterns
developed at the feet, and in the relative velocities of the body and
the load. In the crouch-lift, forces were developed at the feet prior
to lift-off. At lift-off, the body traveled upward faster than the load.
In the stoop-lift, the load traveled faster than the body throughout the
lift. In addition, greater power could be produced by the crouch lift
at the feet. This was due to the simultaneous development of force and
velocity, whereas the stoop lift occurred under isometric conditions.
It was also observed that back extension did not take place uniformly
until the velocity of the body's center of gravity reached a maximum.
In summary, Grieve favored the crouch lift and determined that the highest

TABLE 4

ACCEPTABLE WEIGHT OF LIFT FOR MALES AND FEMALES*

Lift Range		% of Population			Standard Deviation
		75	50	25	
Floor to	Male	49.62	61.17	72.71	16.86
Knuckle Height	Female	32.50	37.12	41.73	6.74
Floor to	Male	42.91	51.21	59.50	12.11
Shoulder Height	Female	26.60	31.03	35.56	6.54
Floor to	Male	41.45	49.12	56.79	11.20
Extended Reach	Female	24.43	28.14	31.84	5.41
Knuckle to	Male	47.42	57.47	67.52	14.67
Shoulder Height	Female	27.48	31.97	36.45	6.55
Knuckle to	Male	46.21	53.54	60.87	10.70
Extended Reach	Female	22.89	26.22	29.55	4.86
Shoulder to	Male	36.46	43.62	50.77	10.45
Extended Reach	Female	22.92	25.78	28.63	4.17

* (weight in pounds)

Source: Ayoub, 1978

stresses during the lift occurred in the first .4 second. He recommended that future research into potentially injurious stress should emphasize this time frame.

Roozbazar (1974) wanted to ascertain the effects of shear and compressive stresses and bending moments on the L4 and L5 vertebrae during three different methods of lift (back bent/knees extended, back vertical/knees bent, back inclined/knees bent). The mechanical analyses used in this study were restricted to statics. The three conditions were instantaneous positions with the load being held against gravity. The experimental situation was limited to two-handed, symmetrical lifting using a 55 kg weight in the sagittal plane, with very little trunk rotation. The results showed that the back erect with knees bent method was superior to the other two lifting methods. Nachemson (1971) and El-Bassoussi (1974) also agreed with these authors by stating that the knees bent/back straight method was superior to the knees straight/back bent technique.

The results of these research efforts would appear to agree with the recommended lift method by the National Safety Council (1974). This lifting technique is called the kinetic method and has the following description:

1. Correct position of feet - feet are parted comfortably for stability, with one foot alongside and the other behind the load.

2. Straight back - a straight back is defined as one where the spine is rigid, and the pressure on the lumbar region is evenly distributed.

3. Arms close to body - the load should be drawn close, and the arms and elbows should be tucked into the side of the body.

4. Correct hold - a full palm grip is used by extending the fingers and the hand around the object to be lifted.

5. Chin in - tuck the chin in so that the neck and head continue to have a straight back line.

6. Body weight - position the body so that its weight is centered over the feet. This provides a more powerful line of thrust and ensures better balance. When lifting the object from the ground, the thrust

from the back foot combined with extension of the legs and back, will move the body forward and upward. The back leg is then moved forward at approximately the same moment the lift is complete.

7. Lift to shoulder height - lift load to waist height, and rest the object on a ledge or hip. Shift hand positions and bend knees for added power. Then, lift the load to the shoulder and straighten the knees.

8. Direction change - lift object to carrying position and then turn entire body, including feet.

The last topic to be discussed in this section deals with a YMCA training program to prevent back injury through physical fitness (Galton, 1978). Snook and Ciriello (1972) believed physical fitness to be one of the more important variables in lifting tasks. The feasibility study for this program was conducted three years ago at several YMCA's in New York City. Presently, this effort is being guided by Hans Kraus, a physician, and Alexander Melleby, a YMCA health and physical education specialist. The back-building regimen consists of 12 sessions under the supervision of a trained instructor. The exercises attempt to relax, limber and tone abdominal, back and other muscles involved in walking, bending, sitting and squatting. The initial results were encouraging - 65% of a sample of 421 claimed good to excellent results.

This effort originally began 30 years ago in New York City at the Columbia-Presbyterian Medical Center. Kraus and another physician, Sonja Weber, developed six exercise tests (Kraus-Weber tests) to determine inadequate muscle strength or flexibility. These tests consisted of a leg raise lying on back, leg raise lying on stomach, sit-up with legs stretched, sit-up with legs bent, trunk raised lying on stomach with legs stretched, and toe touch. Trunk and leg raises were to be maintained for 10 seconds. The failure of one of these tests was accepted as evidence of back weakness. However, passing the six tests only indicated that an individual possessed minimum muscular fitness.

Kraus and Weber initially tested 3,000 patients at the clinic. The results showed that muscular weakness was common among adults. They

both felt that this was tentative evidence that back injury and pain
had a relationship with under-exercised muscles and tension. Another
study indicated that European children, when compared to American
children, had a lower percentage of test failure. Additionally, Kraus,
using the case study approach over his years in private practice, could
show that an exercise program of muscle-strengthening alleviated back
stress. In general, these studies appear to lack experimental control,
however, the idea has face validity and may include a fair amount of
concurrent validity.

Sex Variable

Between 1950 and 1975, the number of women entering the work force
has increased from 29% to 40% of the total working community (U. S.
Bureau of the Census, 1975). As these individuals enter the working
environment, they are assuming more jobs that were previously con-
sidered "male". There are also pressures by government and feminist
organizations to integrate women into these non-traditional jobs. There-
fore, it is necessary that the sex variable be increasingly studied as
women are being added into the working area. Questions concerning
selection, training and human engineering must be answered with these
changes in the work force roles.

A recent article in Human Factors (Hudgens and Billingsley, 1978)
attempted to determine whether research was keeping abreast of this
industrial trend and the concurrent problems it presents. The content
of Human Factors and Ergonomics was analyzed between 1965 to 1976. Of
the 859 studies analyzed, the sample of males only, females only, both
sexes and unknown sex reports represented, respectively, 44%, 6%, 19%
and 31%. The authors concluded from their findings that the increasing
number of women in the work force was not reflected in a higher interest
in the sex variable. Reasons for ignoring this variable, they explained,
could partially be attributed to availability of subjects, increased
time and money to coordinate larger efforts, undesired public attention,
political pressure and more experimental complexity.

The sex variable in the current human factors literature is concerned with (1) the determination of differences between the sexes relating to the capability to perform specific jobs, and (2) the analysis of the effects of biological rhythm upon the working population (Lanfair and Smith, 1974). These two topics will be discussed in the following paragraphs by outlining research articles from the literature. Some of these reports do not directly pertain to lifting. It must be kept in mind, however, that the performance of load handling tasks can be influenced by many variables, such as strength, endurance, motivation and menstrual cycle. For this reason, articles related to these subjects are presented in this section. Also, it must be understood that the literature concerning the sex variable is changing rapidly, and therefore, some of these observed differences may fail to persist with additional research.

Konz (1977) studied the maximum capability of the fifth percentile (5%) American female in strength to actuate manual brakes after experiencing a power brake failure. Two of his calculations are of interest: (1) females have 40 - 60% of the strength of males due to differences in body weight, body composition and training, and (2) ninety-fifth percentile (95%) of pedal force for females can be achieved by the ninety-ninth percentile (99%) of males. McDaniel (1972), Dryden (1973) and Knipfer (1973) were concerned with the establishment of safe lifting limits for both sexes and three ranges of lift. In general, the average weight lifted for females was 55% of the male value. A more recent investigation (Ayoub, 1978) determined that the percentage value for female to male weight in six lift ranges was 57%.

Kumer (1974) compared male and female lifting techniques from floor to table and table to floor lifts. Lumbar vertebrae were observed to be fixed until a critical level was reached. Extension of the spine then began. This level was a function of both weight and sex, with extension occurring later in females and with heavier weights.

Garg (1976) developed a model to estimate metabolic energy expenditure rates for a wide variety of manual material handling jobs. The basic assumption he made was that the average metabolic energy expenditure

rate for a given job can be predicted by knowing the metabolic energy expenditures of the components (tasks) and time duration of the job. His equations could be used to compare the metabolic strain per single lift for 10, 25, 40 pound weights, male and female sex, and squat and arm lifts. These calculations indicated that 40 pounds, male sex and squat lift had higher strain values. Brouha (1960) determined from bicycle ergometer and treadmill tests that females have a 25-30% lower aerobic capacity than men. At a given level of oxygen intake, their heart rates were higher resulting in earlier onset of exhaustion at lower workloads. These findings indicated that females are less fit than men for both moderate and strenuous exertion. Ayoub and Manuel (1966) reported that ventilation rate, when compared by body surface area, averaged 9.6% higher for males than for females when performing light repetitive tasks. Of note, the authors found that there was no significant relationship between ventilation rate and ovulatory cycle.

Griffith and his associates (1950) attempted to determine, from a sample of 24 female office workers and 232 manual, 75 foremen and 48 office male workers, the amount of subjective fatigue during the working hours. Results indicated that older and female workers tended to report being more tired. On this same topic, Spaulding (1964) studied subjective fatigue in 4,000 medical clinic out-patients. Using a definition of fatigue as "a feeling of difficulty in doing things," female patients significantly reported this complaint more often than did men.

Dalton (1969) and Liskey (1972) determined respectively that 52% and 47% of the female accidents in their sample occurred during the menstrual flow or premenstrual phase of the cycle. Baisden and Gibson (1975) reported that perceptual psychomotor performance was not affected by different phases of the menstrual cycle or by oral contraception. These authors further stated that individuals who were prone to complain and have lower stress tolerances would more than likely react to environmental pressure by decrements in performance. They recommended that future study should be conducted into female personality factors which would affect performance under stress.

Finally, there appears to be some evidence that females are more noncompetitive and avoid situations that appear to be competitive. House (1974) reported that females in a competitive situation had lower performance expectancies and confidence than females working alone or males in a competitive condition. Deaux, White and Farris (1975) stated that male undergraduates showed a preference to select games requiring skill and to persist longer at these games. On the other hand, females desired to play games in which luck was the determinant.

Training Variable

The acquisition of skill through training depends upon the interrelatedness of a person's senses (input), cognition (mediation), and motor (output) elements. The appearance of an observed motor act is first perceived by the sense organs, and then through sustained practice, the cognitive qualities and required coordinative potentialities are learned. This process can be seen as a series of building blocks involving increasingly more spatial and postural discriminations which in turn require more differentiated associations of bodily awareness, imagery and memory. The integration of the sense data into a perceptual whole by the central nervous system thereby leads to more effective motor responses. This discourse would tend to indicate that an untrained individual's motor capacities may not be fully recognizable or can not be properly evaluated because of his lack of integrated responses (Jokl, (1968).

To distinguish between the trained and untrained individual, categories and principles of motion must be described. Wartenweiler (1973) stated that body movements can be divided into rotations of limbs around joint axes, translational activity of pushing and pulling, and torsions such as twisting of the spine. Of these, rotations are considered to be the most important. He believed that a theory of movement performance must consider static and dynamic force, speed, frequency, equilibrium, precision, rhythm and coordination.

Rhythm can be defined as a constant variation that occurs at reg-
ular time intervals. Acceleration can be considered to be a sensitive
measurement of rhythm since it can reflect precision control and quality
of motion. Its quality can be analyzed as a continual wave pattern with-
out sudden occurring changes of acceleration and movement (Wartenweiler,
1973; Tichauer, 1973).

Komarek (1968) used the task of sawing wood to illustrate rhythm,
frequency, work completed and the duration of antagonistic muscle
activation as criteria of skill. The goal of training was to eliminate
wrong, unnecessary movements. Acquisition of skill through training,
therefore, was to develop purposeful, accurate and rational activity.
The results indicated that after training: (1) there were less movement
variance and therefore more rhythm, (2) an increase in frequency with an
accompanying increase of completed work, and (3) more effective utili-
zation of the biceps which decreased useless activation of the triceps.
Ronnholm and his associates (1962) compared energy cost in rhythmic and
paced lifting. The results indicated that rhythm improved mechanical
efficiency and was more economical.

Various researchers (Hatze, 1973; Ayoub, 1971; Nubar and Contini,
1961; Beckett and Chang, 1968) have similarly studied optimal human
motion for repeated trial and error activity with the help of mathematical
modeling. The underlying assumption in these studies was that through
repetitions of specific motions under similar environmental conditions
by an average, healthy individual, an adaptation toward efficiency,
economy and optimization would occur. This means that performance would
be maximized under given constraining conditions while energy expenditure,
movement and/or muscular effort would be minimized.

Cinematographic analysis has been used by researchers to analyze the
differences between trained and untrained activity. Waterland (1968)
compared skilled and unskilled broad jumpers. He concluded that the
overt patterns were similar for both groups but that the skilled person
exhibited a totality of response and mobility of body segments not seen
in the unskilled subject. The upper extremities were kept close to the
unskilled individual's body resulting in lowered sensory inputs and

minimal motion of the head and shoulders. Vorro and Hobart (1974) studied the kinematic changes that occurred as proficiency was acquired in an underhand ball toss for accuracy. Throughout the practice periods, changes occurred between the correct and incorrect elements of the task resulting in decreased times of execution and angles of ball release. In other words, motion became more efficient with training. Ariel (1974) used twelve experienced weight lifters in order to determine forces and moments of force acting upon the knee joint during the deep knee bend. This study revealed that the strongest subjects demonstrated less shearing force than did weaker subjects. In addition, training resulted in increased vertical and decreased horizontal forces during lifts.

Muscle activity has also been investigated to determine differences between trained and untrained individuals. Hobart and Vorro (1974) reported that various authors found different results after they investigated the relationship between integrated electrical activity and practices on the acquisition of a novel motor task. Summary of these conflicting conclusions concerning practice effects were:

1. no change (Brush, 1966).

2. an increase (Finley, Wirta, Cody, 1968).

3. decline in one muscle, no change in another (Payton, Kelley, 1972).

4. a shift in activity due to practice. Some muscles increase and others decrease their activity in order to effect smooth performance (Hobart, 1972; Finley and Wirta, 1967).

Because of this confusion in the literature, these two authors decided to study the problem of total integrated electrical activity and timing of muscle response during skill acquisition for an underhanded ball toss. The results indicated that there were no significant changes for total activity, but there was a general trend for both the anterior and posterior muscles to reach peak activity earlier. This trend also significantly decreased the time between the beginning activity of both muscles indicating a change in muscular timing, synchronization and coordination with training.

Other authors have studied the effects of strength training on muscular activity. Cerquigline et al. (1974) and Ashton and Singh (197! noticed that training caused changes, respectively, in mean peak voltages of the quadriceps femoris and gastronemius muscles during weight lifting exercises and of the erector spinae during isometric back lift training. However, the findings of Chapman and Troup (1969) noted no change in activity with strength gains. There are two factors that can cause changes in strength; physiological development and neuromotor pattern response (Laycue, Marteniak, 1971). The observed increases in strength, as reported in this study, could possibly be attributed to higher motor unit activity without there being any growth of muscular tissue. Hoag, Howard and Purswell (1975) studied the effects of isometric strength training on heart rate and blood pressure. The results indicated that there were significant increases in heart rate with increases in strength. There were no consistent changes in blood pressure. In addition, heart rate rose more rapidly during the exercise of the trained individual.

Brouha (1960) can be used at this point to partially summarize research findings as covered in this section. He stated that training increased muscular size and heart efficiency; improved motor unit transmission, motion precision and economy, and cardiovascular recovery; affected blood pressure, respiration and blood distribution.

To conclude this subsection on the training variable, a sequential outline of the various stages of the attainment of skill may be appropriate. Jokl (1968) viewed this development in the following four overlapping stages:

1. Idea of the work - the setting of objectives through personal instruction and/or influential precedent gives the individual a perception of the standards to be attained.

2. Design of the work - there is a reversible link developed between sensory and motor, one decodes the abstracted significant elements and focal points of a pattern and the other codes the impulses involved in initiation and control. Appropriate instruction and training aids assist the individual by filtering the input of these selected

images. Graphic representation of motor performance, for example, can aid in the development of memory traces which will serve as training guides.

3. Constructive plan - sustained practice of a specific sequence of movement is necessary to the establishment of advanced levels of control and precision. The development of a plan, which will coordinate and combine the practice of these parts in order to achieve mastery of the integration whole, is necessary.

4. Motor technique - with increasing skill, motor activity becomes progressively more automatic with the performer and the performance merging into a whole. The motor act now becomes one not only of skill but of personal style.

CHAPTER III

METHOD

This chapter deals with the various methodological aspects involved in this experiment. These considerations will be discussed under: experimental design, training program, data collection and biomechanical model.

Experimental Design

Eight male and eight female Texas Tech students who were similar in age and anthropometric dimensions were used in this experiment as paid volunteers. Initially all sixteen students were considered inexperienced and untrained. An inexperienced/untrained lifter is operationally defined in this experiment as one who does not participate in a regular physical fitness program or exercise routine, use weights, or have a job which involves manual handling of materials. From this sample, four males and four females were selected for the training program while the other eight subjects served as the control group.

Age of the subjects ranged from 18 to 30 with a median of 25 years. Table 5 demonstrates the close anthropometric match between male and female sub-samples by depicting their segmental lengths, heights and weights. Figure 1 is a diagram of the segmental links and centers of gravity of the human body, which is given as an aid to understand Table 5. Additional length measurements of popliteal height (sitting), elbow-fingertip, buttock-knee and shoulder-elbow were taken and compared to distribution statistics contained in Human Engineering Guide to Equipment Design (Van Cott and Kinkade, 1972) for males and Anthropometry of Women of the U. S. Army - 1977 (Churchill et al, 1977) for females. Averages of the four lengths, height and weight for these sixteen subjects indicated that their percentile placements in their respective sex populations were:

	male	female
four length measures	29%	73%
height	30%	85%
weight	15%	65%

TABLE 5

ANTHROPOMETRIC DATA FOR THE EXPERIMENTAL SUBJECTS

Subject no.	Weight (kg)	Height (cm)	Segment Lengths (cm)					
			Ankle/ Knee	Knee/ Hip	Hip/ Shoulder	Shoulder/ Elbow	Elbow/ Wrist	Wrist/ Load
Female: 1	61.4	170.5	40.7	44.3	49.4	30.0	25.6	6.1
2	64.9	168.5	42.6	43.2	47.0	28.4	25.1	6.2
3	63.0	171.4	43.2	42.8	49.1	31.6	26.5	6.5
4	61.4	171.9	42.2	44.5	48.8	31.0	25.8	6.4
5	61.2	171.0	41.6	43.5	49.6	30.5	27.3	6.4
6	65.5	173.1	43.4	43.8	49.2	28.6	25.4	6.4
7	63.9	169.9	39.4	43.9	50.6	27.9	25.5	7.0
8	64.1	176.0	45.8	42.1	50.8	31.5	27.0	6.6
Ave.	63.2	171.4	42.4	43.5	49.3	29.9	26.2	6.5
Male: 9	57.1	174.5	44.8	39.6	51.5	30.7	27.2	7.2
10	64.6	167.9	40.7	41.9	48.2	29.5	26.1	6.4
11	61.4	173.5	43.5	42.9	48.8	30.1	27.3	6.2
12	62.8	172.6	43.7	42.6	48.2	30.8	26.2	6.0
13	59.1	168.3	42.6	39.5	49.0	29.7	25.1	6.0
14	62.6	176.4	43.0	42.9	51.5	31.4	26.5	7.3
15	61.2	170.5	41.0	40.5	51.3	30.4	26.9	6.5
16	64.1	175.9	42.7	42.6	51.7	29.7	27.4	6.5
Ave.	61.6	172.5	42.8	41.6	50.0	30.3	26.6	6.5
Combined: Ave.	62.4	172.0	42.6	42.5	49.7	30.1	26.3	6.5
S.D.	2.2	2.8	1.6	1.5	1.4	1.10	.8	.4

SYMBOLOGY FOR SEGMENT
CENTER OF
GRAVITY

1 = Upper Arm
2 = Lower Arm
3 = Hand
4 = Trunk
5 = Upper Leg
6 = Lower Leg
7 = Foot

SYMBOLOGY FOR SEGMENT
LINKS

A = Height
B = Ankle - Knee
C = Knee - Hip
D = Hip - Shoulder
E = Shoulder - Elbow
F = Elbow - Wrist
G = Wrist - Load
(C. G. of Hand)
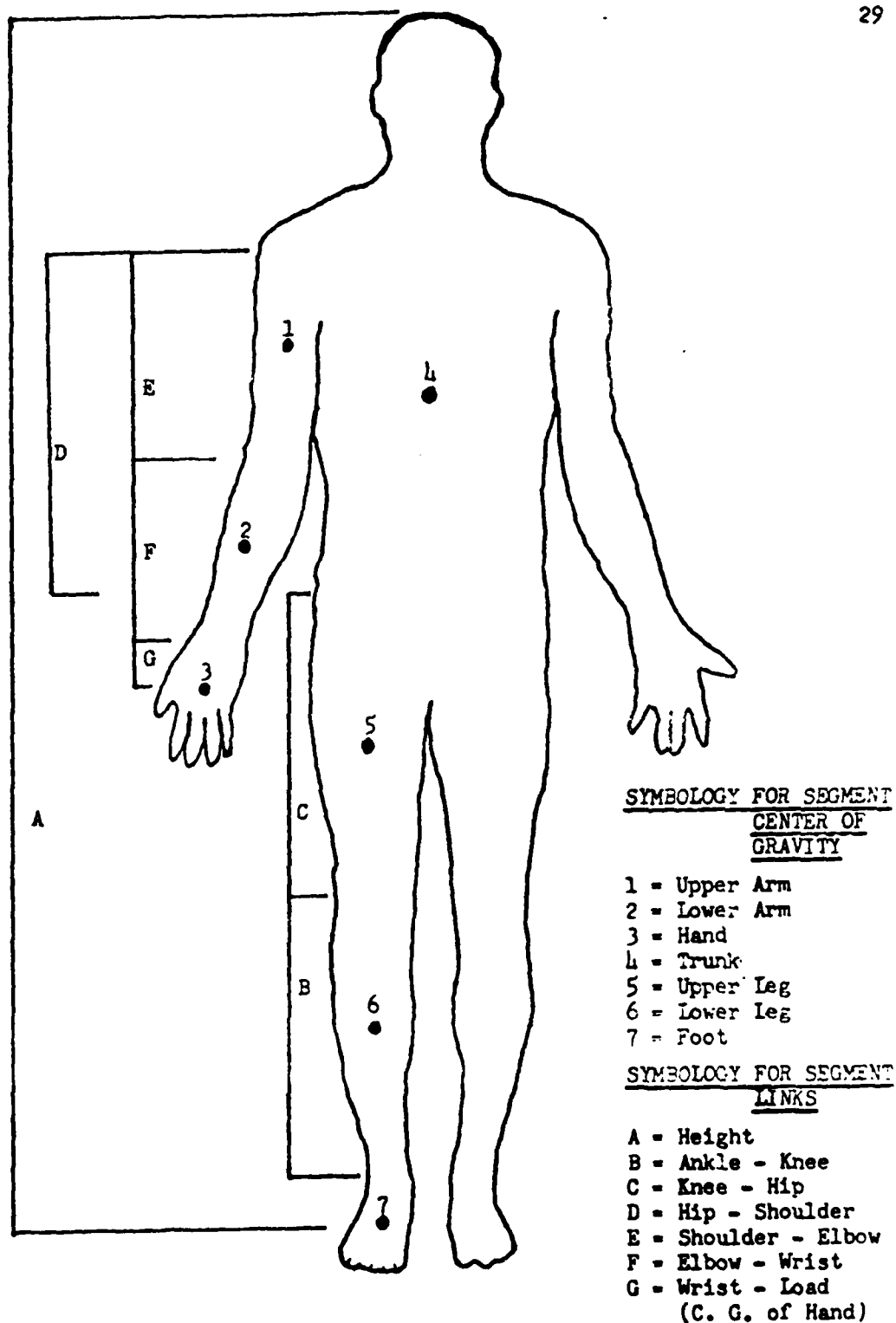
FIGURE 1: Diagram of human body showing segment links and centers
of gravity.

The experiment involved separating these sixteen subjects into two equal replication groups: experimental and validation. After subject selection and designation as to program (control or train), a pre-training period of data collection was commenced on the "experimental" group (N = 8). Each of the subjects were observed under all treatment conditions. Additionally, each subject was instructed as to the purpose of the experiment, the responsibilities of being a subject, and the requirement that the untrained sample could not use weights until after their second measuring session. After completion of the training program, the trained and untrained subjects were again measured. There was approximately a two week interval between pre- and post-measurement sessions. Although data for both replication groups were collected separately, the two training programs and time intervals between measurement periods were similar.

The experiment consisted of two lifting height ranges: floor to knuckle and knuckle to shoulder. These two regimes were selected because previous performance models (McDaniel, 1972; Dryden, 1972) seemed to indicate that different muscles and strategies were being used during these two lifts. In addition, these two regimes were close analogs to industrial handling conditions in the sagittal plane. Examples of this similarity would be the lifting of a box off the floor onto a table, and the lifting of a box off a table onto a shelf.

Three weight conditions were used in the experiment - 10, 25 and 40 pounds. A content analysis on biographical data forms, completed by industrial subjects during a recent experiment (Ayoub, 1973), indicated that 10 and 40 pounds were the median low and high loads handled on their jobs. The 25 pound weight condition was added because of its middle position between 10 and 40 pounds. In addition, the upper limit of 40 pounds could not be increased because of the potential stress involved, especially in females who were untrained on the knuckle to shoulder lift.

Barbells were used in the experiment rather than boxes. The bar was approximately 30 inches long and the weights were placed in the middle of

the bar. The weights were maintained in place by screw-on sleeves. The use of barbells was an attempt to control for possible experimental error. Bulk size and handles would have placed another dimension into the experiment. Both of these problems, however, were easily side-stepped with the use of barbells.

Lights were attached to the joints of each subject. A rotating disc, with set intervals and an open shutter camera, was used to double expose on film the lighted movements of these joints. The increments of the disc were set at .125 second. The approximate total time for each type of lift was 1.25 seconds resulting in 10 observations per lift sequence. However, to facilitate data handling, five increments of .25 second were used in the analysis.

The experimental design was a split-plot repeated measures, SPF pr-quv (Kirk, 1968). This design has two between-block treatments (training and sex) and three within-block treatments (weight, time and measure). This set-up was used to analyze the results of the experimental and validation groups separately. When both groups were combined and analyzed, the experiment became a split-plot repeated measures with three between and three within block treatments (Kirk, 1968). This design can also be called a six factor with repeated measures on three factors (Winer, 1971). The added between-block treatment was called "group" to represent both experimental replications. Also, each subject had two trials per lift and weight. Blocking was conducted at the trial level. The following is a list of the various treatment levels used in the SPF 222.532 design for either the floor-knuckle or knuckle-shoulder lift:

Blocks - Subjects (S); 16 (fixed effects)
          Trials (T); 2 (fixed effects)

Between - Sex (A); 2, male/female (fixed effects)
Subject/ Program (C); 2, train/control (fixed effects)
Trials   Group (F); 2, experimental/validation (random effects)

Within - Time (B); 5, 0 - .25/.26 - .50/.51 - .75/.76 - 1.00/1.01
Subjects/   - 1.25 seconds (fixed effects)
Trials   Weight (D); 3, 10/25/40 pounds (fixed effects)
          Measure (E); 2, pre/post measurement (fixed effects)

With the combined experimental cell size being four (2 subjects each having 2 trials), the number of data points per lift were:

$$A(2) \cdot S(2) \cdot T(2) \cdot C(2) \cdot F(2) \cdot B(5) \cdot D(3) \cdot E(2) = 960$$

The sequence of administration first depended upon the subjects being assigned to a sex/program/group (ACF) combination. The order of weight trials were then randomly selected for each of the four subjects within a combination. There were six possible sequences of weight, with the four subjects being randomly assigned to one of these six permutations. There were no repetitions within an ACF combination. Finally, the two lift regimes of floor-knuckle (F-K) and knuckle-shoulder (K-S) were counterbalanced within each sex/training combination, with the sequence order of weight being the same in each regime. This information concerning order of weight and of lift type for each subject is presented in Table 6. As an example using Female/Control, subject 1 (experimental group, E) lifted weight in the order of 40, 25, 10 pounds, while subject 5 (validation group, V) was given the sequence of 25, 10, 40 pounds. Order of lift type for subject 1 was knuckle-shoulder and floor-knuckle, while subject 5 had the reverse arrangement.

The sequence of administration just explained is very similar to the procedure for a split-plot design recommended by Kirk (1968). The time and measure treatments (B, E) in this study, however, precluded randomization of presentation order due to their sequence being dictated by the experimental design. The order effects over time (treatment B) during a lift were of interest because of the stated goals of studying coordination, rhythm and efficiency. The use of a control group was an attempt to cancel out order differences between pre- and post-measures (treatment E).

Training Program

The training program consisted of two males and two females in each replication group lifting 10, 25 and 40 pound weights in floor to knuckle and knuckle to shoulder lift regimes for fourteen practice periods. During each session, subjects in the training program lifted each weight by regime approximately six to eight times. The lighter weight was

TABLE 6

EXPERIMENTAL SEQUENCE OF WEIGHT AND LIFT TYPE BY SUBJECTS

TREATMENT LEVEL:	EXPERIMENTAL GROUP (f_1) *					VALIDATION GROUP (f_2) *				
	WEIGHT (lbs)			TYPE LIFT **		WEIGHT (lbs)			TYPE LIFT **	
SUBJECT NUMBER (E & V)*	$10(d_1)$	$25(d_2)$	$40(d_3)$	F-K	K-S	$10(d_1)$	$25(d_2)$	$40(d_3)$	F-K	K-S
FEMALE/CONTROL (a_1c_1):										
1 & 5	3	2	1	2	1	2	1	3	1	2
2 & 6	1	3	2	1	2	1	2	3	2	1
FEMALE/TRAINED (a_1c_2):										
3 & 7	3	1	2	2	1	2	1	3	2	1
4 & 8	1	2	3	1	2	3	2	1	1	2
MALE/CONTROL (a_2c_1):										
9 & 13	3	2	1	1	2	1	2	3	1	2
10 & 14	2	1	3	2	1	2	3	1	2	1
MALE/TRAINED (a_2c_2):										
11 & 15	2	1	3	1	2	1	3	2	1	2
12 & 16	3	1	2	2	1	2	3	1	2	1

* EXPERIMENTAL: Subjects 1 - 4, 9 - 12; VALIDATION: Subjects 5 - 8, 13 -16

** LIFT TYPE: Floor-Knuckle (F-K), Knuckle-Shoulder (K-S)

lifted more than the heavier weight. This totaled to approximately 42 lifts per subject per session.

The experimenter was present during all of the training sessions, and aided in the instruction with verbal comment. The training program relied on certain ideas from the literature (items 1-4 from Tichauer, 1973):

1. Avoid unnecessary abduction of the upper arm.

2. Keep the moments acting on the vertebral column low by emphasizing movement toward rather than away from the body.

3. Maintain wrist and forearm alignment while moving the arm.

4. Strive for a musculo-skeletal configuration which would increase biomechanical efficiency.

5. Repetitive trial and error motion should result in an individual's adaptation toward efficiency, economy and optimization (Ayoub, 1971).

6. A lifting method similar to the one recommended by the National Safety Council (1974) was emphasized. This technique relies on balance, initial thrust and keeping the load close to the body.

7. Coordination between and rhythm within body segments were stressed in order to increase motion efficiency (Komarek, 1968).

8. The performance of loosening and stretching exercises prior to each training and experimental session was thought to be necessary in order to avoid injury and to increase body awareness (Galton, 1978).

By emphasizing these rules repeatedly, it was expected that each trained subject would optimize his performance by minimizing unnecessary movements. The goal of the program was to improve technique rather than to have muscular development. There was never any attempt to stress, fatigue or motivate the subject to complete more work than he or she wanted to do or was capable of doing. The trained lift when compared to the untrained one was meant to be purposeful, accurate and rational, and therefore, the more efficient.

Data Collection

Data collection entailed the use of stroboscopic photography, force platform and electromyogram (EMG) methodologies. The equipment consisted

of a still camera, lights and a rotating disc with equally spaced
apertures for photography; a force plate and Beckman Offner Type "R"
dynagraph for force recordings; Sanborn integrating preamplifier (Model
350-3700) and Beckman miniature surface electrodes (½" diameter) for
EMG; and weights and barbell. The data from these lifts were collected
by two people throughout the experiment, one taking pictures and the
other handling the dynagraph and preamplifier.

Lights were taped to the skin at the centers of the hip, knee,
ankle, shoulder, elbow and wrist joints, as well as a light attachment
at the center of the weight. Exact location of these centers were
described by Plagenhoef (1971). He indicated that these positions can
be found by using the skin crease that results from bending the joint.

A still camera, whose lens was placed inside of a box with a
rotating disc of equally spaced openings (.125 second apart), was
manually operated during the experiment. This box rested on a table
with the camera centered at the middle of the subject's body. The
camera's shutter speed was placed on "B" to keep the lens open during
the lifts in order to double expose equally spaced strobe light movements
onto the negatives. Kodak Tri-X pan black and white film was used be-
cause of its sensitivity. The lens' aperture opening was set at "F 11".
A series of pictures had previously been taken under experimental con-
ditions and varying aperture openings in order to determine this "F"
setting. The resulting negatives of the experimental lifts provided
angular displacement-time data from the lighted movements of the joints
and weight. With this information computations of velocity, acceleration
and force profiles were accomplished using El-Bassoussi's biomechanical
model (1974), which is described in the next subsection of this chapter.

Electromyograms in arbitrary units were collected on two muscles -
middle deltoid and rectus femoris. The deltoid is a thick triangular
muscle which covers the shoulder joint. This muscle arises from the
clavicle, acromion process, and the spine of the scapula, and is inserted
into the lateral side of the body of the humerus (Kimber and Gray, 1956).
There are three muscles in this group - anterior, middle, posterior. The
main function of this muscle group is that of shoulder abduction (Kelley,

1971). The rectus femoris is one of four muscles comprising the quadriceps femoris. The rectus muscle arises by two tendons, one from the anterior inferior iliac spine and the other from a groove above the brim of the acetabulum (Kimber and Gray, 1956). The function of this muscle is to extend the knee and flex the hip (Kelley, 1971).

These two groups of muscles have been analyzed by various researchers. Shinno (1968) determined from his studies that the quadriceps femoris was the prime mover to extend the knee; and that in the semi-flexed position, the stability of the knee depended mainly upon this muscle's power. Desipres (1974) studied the effect of saddle height and load on muscle activity during road riding on a treadmill. The results indicated that quadriceps femoris activity intensified with increasing incline slope. Leggett and Waterland (1973) studied anterior and posterior deltoid muscle action during skilled gymnastic movements, while supported by the hands. From previous research, they hypothesized that skilled subjects would use only those muscles necessary to task performance, and that all parts of the deltoid would be active during abduction, flexion, and extension. Their findings indicated that only the posterior deltoid showed activity at all times. Hobart and Vorro (1974) analyzed posterior and anterior deltoid electrical activity during the acquisition of an underhanded ball toss task with the arm extended and the hand pronated. Commencement and peaking of activity for both muscles coincided very closely with the beginning of arm and shoulder movement.

During the experiment, two pairs of miniature electromyographic surface electrodes (Beckman, $\frac{1}{2}$" diameter) were attached to the right side of each muscle so as to measure its activity. Both probes were placed approximately in the center of the muscle (horizontal and vertical), one and one half inches apart, with one directly above the other. The skin of the subjects was throughly cleansed with alcohol prior to placement of the electrodes in order to lower skin resistance. The ground was placed on the clavicle.

A dye marker was used to initially mark the position where the electrodes were to be placed. A paper tracing of these markings was

made using the shoulder and knee joints as reference points. During the second measurement session (post-training), these tracings were copied onto the subject's skin for electrode placement. In this way, electrode attachment was standardized for both observational periods.

The Sanborn integrating preamplifier, Model 350-3700, was used in the area summation mode. This meant that the integrated output voltage curve for each lift represented only the positive input signals. The measurement of muscular activity over time was directly related to the area under the curve. The data were read directly from the graph paper in arbitrary units for each incremental time period.

Prior to collecting electromyographic data, the preamplifier was calibrated to ensure that sensitivity and reading output were the same. Switches and controls were standardized throughout the experiment: sensitivity (1 volt-second), attenuator (X 10), and graph paper speed (1 cm/sec). Two channels were used, one for the medial deltoid and the other for the rectus femoris.

After completion of each measurement session, the subject was told to sit down and relax. Another set of readings in an unstressed condition (legs on chair, hands in lap) were collected. These unstressed curves represented measurement error; such as heart rate, muscular tension and equipment noise. During data analysis, the unstressed muscular baselines were subtracted from the stressed muscular outputs.

A Beckman Offner Type "R" dynagraph and force platform were used to record force changes at the feet in arbitrary units over time in three reference planes - sagittal or frontal (forward/backward), coronal or lateral (left/right), and transverse or vertical (up/down). Prior to data collection, the "experimental position" was marked on the platform, which then functioned as a reference throughout the session. This position was found by:

1. locating the intersection of the force platform's center and the subject's mid-sagittal and coronal planes.

2. having the subject stand erect in a balanced position with feet comfortably apart.

The three channels on the dynagraph were then zeroed and the paper speed set at 1 cm/sec.

Data output was in terms of shifting force (+ and -) across a zero baseline. This baseline was either the initial or final positions, respectively, for the knuckle-shoulder or floor-knuckle lifts. In this way, the "experimental position" plus weight became the reference baseline. The amount of peak variations above and below the line within each of the five time intervals were converted from arbitrary units to pounds of force. These conversion estimates had been previously determined using static weights to calibrate the force platform in each of the three planes. The study of peak forces from the platform were previously used by other researchers at Kansas State University (Desai, 1976; Parker, 1976; Perkins and Konz, 1974). The positive and negative changes in each reference plane on the recording paper represented force changes in specific directions. These directions are listed below:

	positive	negative
Frontal	backward	forward
Lateral	right	left
Vertical	downward	upward

Various experiments at Kansas State University have used the same force platform to determine the effects of weight and distance from center of platform (Desai, 1976); height of movement, angle of bodily rotation and box volume (Parker, 1976); height of lift, weight of box and box distance from center of gravity of the subject (Perkins and Konz, 1974). Six types of data were recorded continuously on this platform during a lift: forces in the frontal, vertical and lateral axes, and torques about these axes. The platform is zeroed for body weight with the subject standing motionless in the middle. The results of these investigations can be summarized as follows (Desai 1 - 3, Parker 4, Perkins et al, 5 - 8):

1. Vertical forces for the three weight conditions (5, 10, 15 kg) were significantly different in the floor to knuckle lift.

2. Vertical force increased as weight lifted increased.

3. Bend lift was recommended because the distance between body and load were minimized.

4. Forces and torques decreased with height of movement, and increased with box volume and angle of bodily rotation.

5. The change in box weight from 11 to 22 pounds caused a minimal increase in vertical peak force from 44.9 to 48.1 pounds.

6. Height of lift and initial height position were important variables in the experiment.

7. For lifts in the sagittal plane, peak vertical force was more important than frontal or lateral forces.

8. Peak forces occurred in the .5 second before and after grasp-the load.

In another experiment force platform and oxygen consumption were used to analyze the walking gait in terms of patterns and magnitudes of force (Ismail, 1968). Five measures were used - frontal, lateral, and vertical forces; composite force (square root of the summation of the three forces squared); and total force (sum of three forces). The t-test was used to compare the force patterns of the different ages and body builds, while correlational procedures were employed in determining the best predictors of energy cost using force variable data. The following conclusions were observed:

1. Age and weight variables influenced the magnitude of the forces.

2. Total force, followed by vertical and composite, were the best discriminators between subjects.

3. Oxygen consumption was predicted by force platform and bodily physique data.

The last topic of discussion in this section is the experimental procedure. Prior to the placing of electrodes, the subject was allowed a familiarization or warm-up period of 15 minutes, which involved calisthenics and lifting each weight (10, 25, 40 lbs.) three times in each height regime. This meant a total of eighteen lifts. This warm-up phase was an experimental attempt to avoid subject differences between trials. Each individual was then connected with electrodes and positioned on the force platform. Following this, the equipment was calibrated and checked.

During the experiment, each person performed three lifts with each weight in each regime. There was a total of 18 lifts per subject. The

first lift was a practice one, while data were collected on the second
and third lifts. The sequence of weight lifted by one subject was
randomly selected, and maintained across both regimes. At each weight
level, both lifts were observed prior to proceeding to the next experi-
mental weight condition.

When the observations involved the floor to knuckle lift, each
person was told to crouch to a comfortable position with the barbell
weight on the floor. On the word "Go", the subject proceeded to lift
the weight to a knuckle height. He or she then halted, relaxed and let
the experimenter take the weight. The load was placed on the floor.
After a time lapse of one minute, this procedure began again.

When the knuckle to shoulder was the observed regime, the weight
was handed to the individual at knuckle height. On the word "Go",
the subject lifted the weight to a shoulder position. He or she then
halted, and waited for the experimenter to take the weight. After one
minute, the procedure began again. In this way, 18 lifts encompassing
three weight conditions and two regimes were completed with rest
periods between trials.

Biomechanical Model

A model is a representation of an object or system. This repre-
sentation should reasonably explain, measure, or predict reality with
some degree of accuracy while still being simpler than the imitated
system (Ayoub, Dryden, McDaniel, 1974). The model to be discussed is
one that determines inertial forces and linear accelerations at
various segments of the body during a dynamic motion task, such as
lifting weight. The model's rationale and equations, as used in the
present paper, were previously developed by El-Bassoussi (1974).

In order to simplify the dynamic analysis of the data, the
following assumptions were made:

1. The human body is composed of rigid links.

2. These links are joined at articulation points or joints.

3. The lower arm and hand, because they remain aligned during
motion, were considered as one link in the analysis. The same was true

of the arm during the floor-knuckle lift and leg during knuckle-shoulder lift, since the upper and lower portions of these appendages moved similarly.

4. The density and geometrical shape of a segment remained uniform throughout the lift.

5. Rotation occurred only about the sagittal plane.

6. Segmental motion was considered circular and the radius of rotation was constant.

7. Displacement between the joints and their connecting links was negligible.

8. The ankle remained fixed in one position throughout a lift.

The first step in determining the linear accelerations and inertial forces was to analyze the film negatives which were collected during the experiment. The negatives were presented as slides on a wall by means of a projector. A white piece of paper was affixed to the wall. The projection of the lighted joints were then traced onto the paper. Every other light per joint was marked to represent .25 second time intervals. These marks were then joined, which produced a stick drawing of the body moving over time. Angular displacements were found by measuring the angles between each joint's segments. In all, each floor-knuckle lift had six angular displacements (0, .25, .5, .75, 1.0, 1.25 seconds) for each of the following joints - ankle, knee, hip and shoulder. The knuckle-shoulder lift collected data on the ankle, hip, shoulder and elbow joints.

The use of a fixed total time of motion was determined by measuring all of the times in both lifts. A value was selected (1.25 secs.) which included 75% of all the data. The 25% of the data that deviated from the set limitation were not that much above the 1.25 second value to significantly change the results. In addition, most of the remaining 75% of the total data terminated motion within the final time interval of 1.00 to 1.25 seconds. The total time used in the analysis of each segment, therefore, was the total difference between start and end of motion or 1.25 seconds.

El-Bassoussi's (1974) handling of the total time parameter is in general agreement with the strategy used in this study. Although his

investigation was concerned with continuous data from a motion camera
and the present report studied discrete time intervals, data analyses
in both cases appear to be similar. He used the Slote and Stone (1963)
equations to study the leg lift (similar to floor-knuckle and knuckle-
shoulder lifts combined) only during the following average ranges:

Knee joint - from 0% to 80% of total lift time

Hip joint - from 0% to 85% of total lift time

Shoulder joint - from 5% to 100% of total lift time

Elbow joint - from 15% to 92% of total lift time

Wrist joint - from 12% to 88% of total lift time

Velocity and acceleration were zero, therefore, on either side of these
average ranges for a particular articulation. The present study selected
five fixed time intervals (0 - .25, .26 - .50, .51 - .75, .76 - 1.00,
1.01 - 1.25 seconds) in order to avoid some of the problems associated
with the analysis of continuous data and to facilitate data handling.

The displacement - time relationship of Slote-Stone (1963) was used
in the next phase of the calculations. Instanteous angular displacement
during forearm flexion is seen in this equation as being of equal
increments of total displacement in radians. These increments of
displacement are determined from the relationship between the incre-
mental time period to total time of movement. Angular velocity and
angular acceleration are the first and second derivatives with respect
to time of the angular displacement equation. Angular velocity is
described as increasing from zero to a maximum and then decreasing to
zero. Angular acceleration, on the other hand, is seen in two periods
of zero to maximum to zero. These periods are called acceleration and
deceleration. El-Bassoussi (1974), by comparing his observed experi-
mental displacements with the predicted angles, demonstrated that the
Slote-Stone space-time relationship was valid for the determination of
angular displacement. These equations are as follows:

$$\text{Angular Displacement (time i)} = \frac{D_{max}}{2\pi} \left(\frac{2\pi t_i}{T} - \sin \frac{2\pi t_i}{T} \right)$$

$$\text{Angular Velocity (time i)} = \frac{D_{max}}{T} \left(1 - \cos \frac{2\pi t_i}{T} \right)$$

$$\text{Angular Acceleration (time i)} = \frac{2\ D_{max}}{T^2} \sin \frac{2\pi t_i}{T}$$

where; D_{max} = maximum angular displacement, radians

T = total displacement time, seconds

t_i = incremental time, seconds

Since lifting tasks are circular, instantaneous acceleration can be divided into two components, normal and tangential. The normal component's vector is parallel to the segment's frame but is directed toward the center of rotation. The value of the normal component is equal to the product of the radius of curvature and the angular velocity. The tangential component's vector is tangent to and in the direction of the rotational axis. Its value is equal to the product of the radius of curvature and the angular acceleration. In addition, each component of instantaneous acceleration can be separated into the horizontal and vertical planes. Figure 2 depicts the separation of the angular acceleration for the lower leg during the floor-knuckle lift into these six components and planes. Signs for the direction of these accelerations have the following pattern: y-axis is positive up and negative down; x-axis is positive backward and negative forward. The combinations of the x and y planes for the normal and tangential components form the linear accelerations for each of these axes. As an example using Figure 2, both of these equations for the lower leg are:

Linear Acceleration,

X Axis $= \text{rad}\left[(\text{ang acc})\sin(\text{angle})+(\text{ang vel})^2\cos(\text{angle})\right]$

Linear Acceleration,

Y Axis $= \text{rad}\left[(\text{ang acc})\cos(\text{angle})-(\text{ang vel})^2\sin(\text{angle})\right]$

where; rad = radius of curvature, cm

angle = transformed angular displacement, radians

ang vel = angular velocity, cm/sec

ang acc = angular acceleration, cm/sec^2

The angles used in the above equation are transformed from the angular displacement values (z_i). These transformations measure the
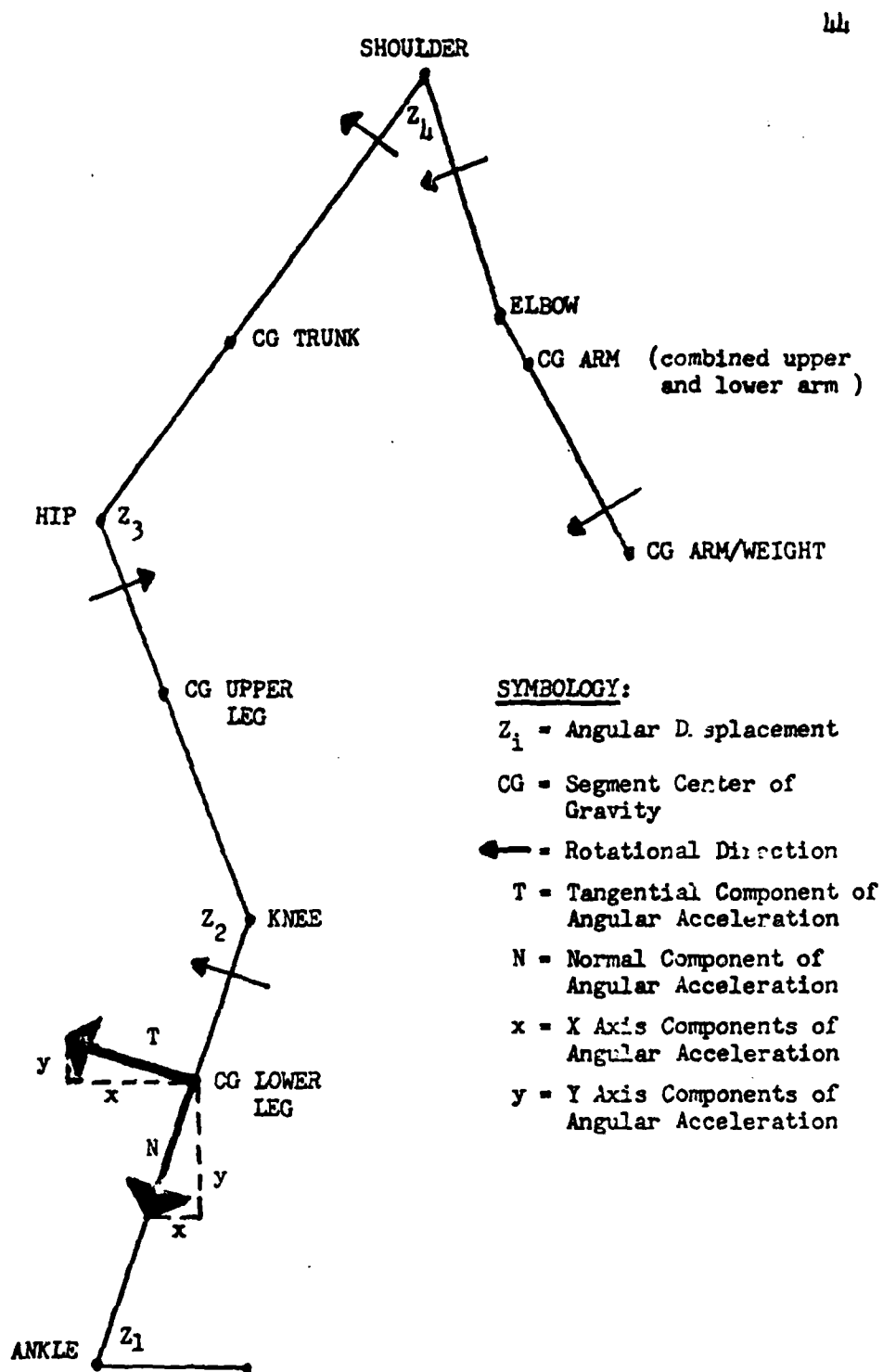
FIGURE 2. Floor to knuckle lift containing angular displacements,
directions of rotation, centers of gravity for each
segment, translational acceleration for the lower leg.

angles between the horizontal axis and the next highest segment. These values in radians are determined as follows:

angle, ankle $= Z_1$

angle, knee $= Z_2 -$ angle, ankle

angle, hip $= Z_3 -$ angle, knee

angle, shoulder $= 180 - Z_4 -$ angle, hip

In order to determine radius of curvature, two measures are used - segment length and distance to center of gravity. Center of gravity values are determined from percentages of segment length. These percentiles are taken from data published by El-Bassoussi (1974). Center of gravity lengths are:

lower leg (LL); $r_1 = R_1$ (.567)

upper leg (UL); $r_2 = R_2$ (.567)

trunk (TR); $r_3 = R_3$ (.396)

arm (A); $r_4 = R_4$ (.530)

arm/wt (W); $r_5 = R_4 +$ wrist to weight distance

where; $r =$ distance from articulation to center of gravity

$R =$ segment length, distance between both joints.

As mentioned previously, linear acceleration is found by combining tangential (T) and normal (N) components in either x or y planes. Using a shortened version of the linear acceleration equation depicted previously, the computations for each of the segments are:

X axis accelerations -

LL (r) or LL (R) $= r_1$ or R_1 (T + N)

UL (r) or UL (R) $= r_2$ or $R_2 [- (T + N)]$

TR (r) or TR (R) $= r_3$ or R_3 (T + N)

A (r) $= r_4$ (T + N)

W (r) $= r_5$ (T + N)

Y axis accelerations -

$$LL\ (r)\ or\ LL\ (R) = r_1\ or\ R_1\ (T - N)$$

$$UL\ (r)\ or\ UL\ (R) = r_2\ or\ R_2\ (T - N)$$

$$TR\ (r)\ or\ TR\ (R) = r_3\ or\ R_3\ (T - N)$$

$$A\ (r) \qquad\qquad = r_4\ [\ -(T - N)\ ]$$

$$W\ (r) \qquad\qquad = r_5\ [\ -(T - N)\ ]$$

where; T = tangential component; T in X plane = (ang acc) sin (angle);
and T in Y plane = (ang acc) cos (angle)

N = normal component; N in X plane = (ang vel)^2 cos (angle);
and N in Y plane = (ang vel)^2 sin (angle)

Since linear acceleration of a particular segment is due to its rotation about all preceding joints, these acceleration values are:

$$LL = LL\ (r)$$

$$UL = LL\ (R) + UL\ (r)$$

$$TR = LL\ (R) + UL\ (R) + TR\ (r)$$

$$A = LL\ (R) + UL\ (R) + TR\ (R) + A\ (r)$$

$$W = LL\ (R) + UL\ (R) + TR\ (R) + W\ (r)$$

The final computations were those of inertial force at each of the links in the x or y planes. Important to these calculations is the determination of segment weight from data published by Plagenhoef (1971). These values are percentages of total body weight by segment and are as follows:

	Males	Females
hands	1.3	1.0
forearm	3.8	3.1
upper arm	6.6	6.0
lower leg	9.0	10.5
upper leg	21.0	23.0
trunk	38.1	46.6

At each link, inertial force is found directly from its weight. In the case of the hand holding the load, the additional value of either 10, 25 or 40 pounds would be added to the weight of the hand as follows:
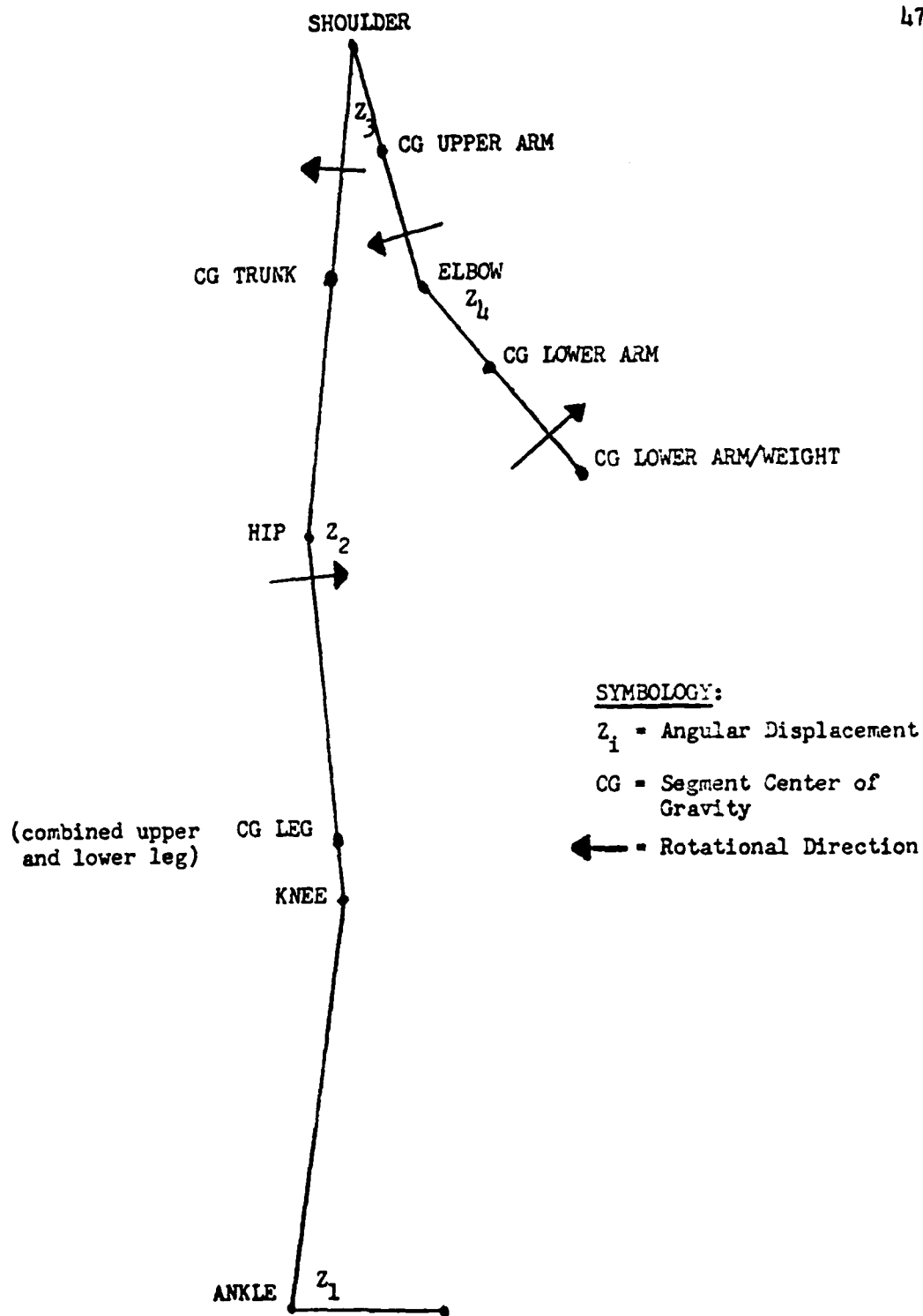
FIGURE 3: Knuckle to shoulder lift containing angular displacements, directions of rotation, centers of gravity for each segment.

$$\text{Inertial Force, X axis} = - \left(\frac{W(H) + W(L)}{980.616}\right)(\text{lin acc, X})$$

$$\text{Inertial Force, Y axis} = - \left(\frac{W(H) + W(L)}{980.616)}\right)(\text{lin acc, Y})$$

where; W(H) = weight of hand

W(L) = weight of load

lin acc, X = linear acceleration, X axis

lin acc, Y = linear acceleration, Y axis

Figure 3 depicts the knuckle to shoulder lift. The leg is treated as one segment due to the relatively small movement at the knee joint. Since this material is very similar to the floor to knuckle procedure, the information will be presented briefly:

1. The angles used in the linear acceleration equation are determined by -

angle, ankle = Z_1

angle, hip = Z_2 - angle, ankle

angle, shoulder = 180 - Z_3 - angle, hip

angle, elbow = angle, shoulder + Z_4 - 180

2. The center of gravity lengths are -

leg (L); r_1 = R_1 (.533)

trunk (TR); r_2 = R_2 (.397)

upper arm (UA); r_3 = R_3 (.436)

lower arm (LA); r_4 = R_4 (.430)

lower arm/weight (W); r_5 = R_4 + wrist to weight distance

where, r = distance from articulation to center of gravity

R = segment length, distance between both joints.

3. The shortened versions of the linear acceleration equations are -

X axis accelerations -

L (r) or L (R) = r_1 or $R_1 [- (T + N)]$

TR (r) or TR (R) = r_2 or R_2 (T + N)

$$UA\ (r)\ or\ UA\ (R) = r_3\ or\ R_3\ (T + N)$$

$$LA\ (r) = r_4\ [- (T - N)\,]$$

$$W\ (r) = r_5\ [- (T - N)\,]$$

Y axis accelerations -

$$L\ (r)\ or\ L\ (R) = r_1\ or\ R_1\ (T - N)$$

$$TR\ (r)\ or\ TR\ (R) = r_2\ or\ R_2\ (T - N)$$

$$UA\ (r)\ or\ UA\ (R) = r_3\ or\ R_3\,[- (T - N)]$$

$$LA\ (r) = r_4\ (T + N)$$

$$W\ (r) = r_5\ (T + N)$$

where, T = tangential component; T in X plane = (ang acc) sin (angle); and T in Y plane = (ang acc) cos (angle)

N = normal component; N in X plane = $(ang\ vel)^2$ cos (angle); and N in Y plane = $(ang\ vel)^2$ sin (angle)

4. The linear accelerations for each segment are presented below -

$$L = L\ (r)$$

$$TR = L\ (R) + TR\ (r)$$

$$UA = L\ (R) + TR\ (R) + UA\ (r)$$

$$LA = L\ (R) + TR\ (R) + UA\ (R) + LA\ (r)$$

$$W = L\ (R) + TR\ (R) + UA\ (R) + W\ (r)$$

5. The formula for the inertial force in either x or y planes is -

$$Force = -\ \left(\frac{Weight}{980.616}\right)\left(\begin{array}{c}linear\\acceleration\end{array}\right)$$

The percentiles to determine link weight have previously been presented.

The resulting data in either lift, after completing these computations, were linear accelerations and inertial forces by time interval and segment. The only force data examined in depth were the stress patterns at the hands.

CHAPTER IV

RESULTS AND DISCUSSION

The statistical approach used in this experiment is similar to
that recommended by Finkelman and his associates (1977). He claimed
that multiple ANOVA's applied to simultaneous multimodality measures
often result in excessive alpha error, loss of experimental error and
loss of information due to interdependence of dependent variables. He
recommended that multivariate analysis of variance (MANOVA) be used in
combination with univariate F tests and/or discriminate analysis.
Finkelman considered MANOVA to be a screening device which could test
the aggregate effect of each independent variable on a set of dependent
variables. The post-comparison techniques would then evaluate the
impact of significant independent variables on each of the dependent
measures.

The combined method of factor analysis, analysis of variance, and
Tukey and t-test multiple comparison analyses were used in the present
study to avoid the pitfalls just described and to increase experimental
power, accuracy and validity. The factor analytic procedure was
performed in order to determine similarities or clusters among the
variables, as well as to erect a structure or classification model to
ease the burden of analysis and interpretation. Fifteen dependent
variables in each lift regime were collapsed to five dependent factor-
variables (2 floor-knuckle, 3 knuckle-shoulder). Factor scores from
these analyses were then studied by the ANOVA tests. These scores are
similar to a multiple linear regression model. The loadings are
utilized as beta weights and multiplied by the case's standard score
on each variable. Each case's score for a given factor is the sum of
these products.

Five split-plot analysis of variance tests for the five factors
were performed separately on each replication group: experimental,
validation and combined. Simple mean effects and Tukey tests functioned
to limit the scope in the analyses that followed by determining

significant effects between independent and the dependent factor-variables. The t-tests then evaluated the influence of the original 15 variables within each of the significant factor-variable by treatment combinations.

Additional statistical tests were used in this investigation. Stepwise regression analyzed the 15 dependent variables in both regimes as predictors of force patterns at the hands in the x and y axes. The Kolmogorov-Smirnov, Fisher Z function and Spearman "rho" test attempted to validate, respectively, the biomechanical model, the correlational matrices and the factor structure.

Various authors (Donskoi, 1973; Zatsiorsky, 1973; Donskoi et al, 1974) have applied multivariate statistics of correlation, regression, factor and discriminate analyses to develop their biomechanical models. The underlying principle used in their studies was that individual segment motion is a part of a phase of motion, and that the combination of all phases represent the total system of activity. The system can be improved only through understanding the interrelatedness of the various phases and components. With this knowledge, the athlete could focus on the most important part of the motor act. Two types of efficiency estimation of sport techniques based on these relationships of movement were used:

1. assessment of heterogeneous characteristics by comparing performance to top-class athletes or a biomechanical standard.

2. assessment of homogeneous characteristics by comparing an athlete's observed and predicted performance.

These two comparisons relied, respectively, on discriminate analysis and regression analysis. Although these techniques were used to assess athletic performance, they could also be applied in the investigation of other types of biomechanical problems such as lifting.

Another paper (Kirjonen, 1968) used factor analysis, factor scores and analysis of variance to study gross motor performance in connection with certain parameters of physical fitness. The results indicated that the method had good applicability in the study of biomechanical data.

Roozbazar (1973) emphasized the use of more multivariate analysis in his review of various approaches to biomechanical modeling. He stated that the human body cannot be modeled without over simplication because of its complexity. To adequately study the human subsystem, he recommended that more multivariate studies be conducted which would analyze the relationships between the biomechanical, physiological, environmental and occupational factors. In this way, comfort boundaries and tolerance limits for human activities could be established, as well as validating existing methodologies and models.

The remaining portions of this Chapter will attempt to demonstrate that:

(1) there are differences in lifting techniques between males and females and the trained and untrained conditions.

(2) inertial forces at the hands can be predicted.

(3) the results in this study are valid.

To accomplish these goals, this Chapter will be divided into the following subsections: biomechanical model validation, multivariate analysis, analysis of variance, and t-test comparisons.

Biomechanical Model Validation

El-Bassoussi (1974) stated that the Slote and Stone (1963) equation predicted information that was similar to his experimental data at every link. Ayoub (1971) performed a sensitivity analysis on Dempster's (1955) percentage values of total body weight by segment. The percentage values were varied by ± 20%, which resulted in only minor changes to the model's predictions. Both of these findings lend credibility to the model presented in this report. Further analyses demonstrating model validity were performed using the Kolmogorov-Smirnov test and regression analysis.

The Kolmogorov-Smirnov one sample test is a test of goodness of fit. The analysis is concerned with the amount of agreement between the cumulative frequency distributions of observed scores and theoretical values. This test determines the point at which the two distributions show the greatest divergence. An "alpha" level of

significance was set at .05 so as to determine whether this divergence would occur if the observations were really a random sample (Siegel, 1956).

The results of these tests are depicted in Table 7. Cumulative distributions were calculated by dividing the angular displacements per time interval by the total angular displacement, both in degrees. Using a sample size of five to conform with the number of observation cells, all but one of the distributions (ankle, floor-knuckle) were nonsignificant at the .05 level (.05 = .565). Maximum deviations were observed in all cases but one (ankle, knuckle-shoulder) to occur at time interval two (.26 - .50 second). Deviation at the ankle in the floor-knuckle lift was not considered very serious, having a maximum difference of nine degrees between both distributions and a total displacement of thirteen degrees.

Another series of Kolmogorov-Smirnov tests were used to evaluate the resultant forces in the x and y planes as measured from the force platform and film negatives. The square roots of the sum of squares, of the peak forces in the sagittal (x axis) and transverse (y axis) planes and inertial forces at the hands in the x and y ares, were calculated for each time interval in both regimes. Force direction was not of interest in these analyses, only overall resultant force in kilograms. Table 8 depicts the results of these two sample tests in both lifts. These calculations indicate that both samples had similar cumulative distributions at the .05 level (.05 = 1.00, using five cells) with maximum deviations occurring at time intervals three (floor-knuckle) and four (knuckle-shoulder).

The second statistical test selected to demonstrate model validity was stepwise regression. Forces at the hands in the x and y planes were used as the criterion variables, while electromyogram and force platform data functioned as the predictors. The resulting correlations which are contained in Tables 11 through 14, were all highly significant. This topic will be further explained in the next subsection of this Chapter.

To summarize, the results of these tests have shown that the Slote and Stone equations can be used to determine angular velocity and

TABLE 7

KOLMOGOROV-SMIRNOV TEST OF JOINT DISPLACEMENT - TIME RELATIONSHIP FOR ACTUAL VERSUS THEORETICAL DATA DURING FLOOR-KNUCKLE AND KNUCKLE-SHOULDER (COMBINED GROUP) LIFTS

Joint Displacement Differences Over Time

Floor-Knuckle:

Distribution Categories	Ankle					Knee					Hip					Shoulder				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Observed Displacements (Degrees)	7	6	0	0	0	16	15	8	4	2	18	41	42	23	9	16	28	26	12	4
Observed Cumulative Distribution (%)	.54	1.0	1.0	1.0	1.0	.36	.69	.87	.96	1.0	.14	.45	.77	.94	1.0	.19	.52	.82	.96	1.0
Theoretical Cumulative Distribution(%)	.08	.31	.70	.93	1.0	.04	.31	.69	.96	1.0	.05	.31	.69	.95	1.0	.05	.31	.70	.95	1.0
Difference	.46	.69	.30	.07	0	.32	.38	.18	0	0	.09	.14	.08	.01	0	.14	.21	.12	.01	0

Knuckle-Shoulder:

Distribution Categories	Ankle					Hip					Shoulder					Elbow				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Observed Displacements (Degrees)	0	1	1	0	1	4	7	1	0	2	3	8	8	5	2	35	29	22	13	6
Observed Cumulative Distribution (%)	0	.33	.66	.66	1.0	.29	.78	.85	.85	1.0	.12	.43	.74	.93	1.0	.33	.61	.82	.94	1.0
Theoretical Cumulative Distribution(%)	0	.33	.66	1.0	1.0	.07	.28	.71	.92	1.0	.04	.31	.69	.96	1.0	.05	.31	.70	.96	1.0
Difference	0	0	0	.34	0	.22	.50	.14	.07	0	.08	.12	.05	.03	0	.28	.30	.12	.02	0

TABLE 8

KOLMOGOROV-SMIRNOV TEST OF RESULTANT FORCE DIFFERENCES OVER TIME BETWEEN FORCE PLATFORM
AND PHOTOGRAPHY DATA FOR BOTH (COMBINED GROUP) LIFTS

Distribution Categories	Floor-Knuckle Lift by Time					Knuckle-Shoulder Lift by Time				
	1	2	3	4	5	1	2	3	4	5
Resultant Peak Forces From Force Platform (kg)	5.66	11.48	5.36	11.05	5.85	3.20	2.92	3.12	3.30	1.67
Resultant Forces at Hand From Film (kg)	7.46	8.17	4.13	6.91	0	1.70	2.50	2.57	2.22	0
Cumulative Distribution From Force Platform (%)	.14	.44	.57	.85	1.0	.23	.43	.65	.88	1.0
Cumulative Distribution from Film (%)	.28	.59	.74	1.0	1.0	.19	.47	.75	1.0	1.0
Difference	.14	.15	.17	.15	0	.04	.04	.10	.12	0

acceleration. Although there are slight differences between observed and expected data, the deviations are not considered large enough to appreciably affect the results.

Multivariate Analysis

Correlational, stepwise regression and factor analysis were performed on each replication group separately (the experimental and validation samples). After each of these three types of statistical analysis were demonstrated to be similar for both groups, the data were combined and the tests were performed again. Results of the first series of tests, the combined group's correlational matrices for both lift regimes, can be seen in Tables 9 and 10. The biomedical computer program package, BMD 02 R (Dixon, 1974), was used in this part of the investigation. The variables and their abbreviated symbols, as presented in these tables, are listed below:

(1) electromyograms in arbitrary units - quadriceps rectus femoris (QUAD), medial deltoid (DEL).

(2) peak forces at the feet in kilograms from the platform - sagittal (SAG), coronal (COR), transverse (TRAN).

(3) segment accelerations in the x and y axes in centimeters per seconds squared from photographic analysis - lower leg (LL-X, LL-Y), upper leg (UL-X, UL-Y), leg (LEG-X, LEG-Y), trunk (TR-X, TR-Y), upper arm (UA-X, UA-Y), lower arm (LA-X, LA-Y), arm (ARM-X, ARM-Y), hand or weight (HD-X, HD-Y).

(4) inertial forces at the hands in kilograms in the x and y axes from photographic analysis - x axis force (F-X), y axis force (F-Y).

The Fisher Z function (Garrett, 1966) was used to determine the similarity between the matrices of both the experimental and validation groups in the two lifts. This test, similar to a t-test, compares the difference between two correlations in the numerator. The denominator contains the square root of the summation of the reciprocal of each sample size minus three. Since multiple t-tests increase the probability of arriving at inaccurate results, the "alpha" level was set at .001 (t = 3.30) for each comparison. The probability, therefore, of having one inaccurate judgment of significance when in fact it was

TABLE 9

CORRELATIONAL MATRIX FOR THE FLOOR-KNUCKLE LIFT

VARIABLES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. QUAD	1.0	.14	-.11	-.02	.18	.24	-.22	-.03	.14	.17	.05	.04	.13	.17	.18	.18	.19
2. DEL		1.0	-.03	-.13	.05	.07	-.08	.01	.06	.06	-.08	-.09	.00	.04	.05	.06	.08
3. SAG			1.0	-.22	-.31	-.47	.28	.08	-.19	-.23	.10	-.09	-.32	-.37	-.37	-.23	-.35
4. COR				1.0	.31	.23	-.26	.10	.24	.24	-.06	.00	.11	.14	.15	.21	.10
5. TRAN					1.0	.57	-.60	.39	.71	.72	-.22	-.11	.18	.32	.39	.63	.29
6. LL-I						1.0	-.74	-.01	.60	.70	.08	.27	.59	.66	.69	.63	-
7. UL-I							1.0	-.04	-.62	-.69	.07	.00	-.37	-.46	-.49	-.60	-
8. TR-I								1.0	.72	.58	-.42	-.45	-.44	-.30	-.19	.51	-
9. ARM-I									1.0	.97	-.26	-.18	.09	.25	.35	.85	-
10. HD-I										1.0	-.17	-.07	.25	.40	.48	-	-
11. LL-Y											1.0	.82	.58	.41	.35	-	.32
12. UL-Y												1.0	.77	.64	.58	-	.52
13. TR-I													1.0	.95	.89	-	.80
14. ARM-Y														1.0	.98	-	.87
15. HD-Y															1.0	-	-
16. F-X																1.0	-
17. F-Y																	1.0

(Probability for significance, 960 cases: .05 = .09; .01 = .12; .001 = .15)

(A dash in the matrix signifies that a correlational test was not conducted)

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TABLE 10

CORRELATIONAL MATRIX FOR KNUCKLE-SHOULDER LIFT

VARIABLES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. QUAD	1.0	.28	.05	-.02	.00	.03	.06	.06	.07	.07	.05	.00	-.06	-.01	.03	.06	.01
2. DEL		1.0	.05	-.11	.08	.14	.17	.16	.16	.12	.17	.00	-.14	.03	.08	.16	.04
3. SAG			1.0	.09	.33	.12	.21	.13	.20	.26	.05	-.03	-.10	.13	.19	.27	.19
4. COR				1.0	.25	-.16	-.15	-.15	-.07	.05	-.17	-.19	-.08	.13	.17	.02	.20
5. TRAN					1.0	.13	.23	.22	.26	.31	.01	-.11	-.01	.39	.45	.30	.44
6. LEG-X						1.0	.84	.58	.54	.39	-.11	-.06	-.11	.08	.12	.40	-
7. TR-X							1.0	.88	.77	.51	-.02	.04	-.07	.14	.18	.56	-
8. UA-X								1.0	.86	.46	.03	.08	-.04	.11	.14	.55	-
9. LA-X									1.0	.81	-.02	-.01	-.09	.06	.10	.81	-
10. HD-X										1.0	-.06	-.11	-.11	.09	.14	.14	-
11. LEG-Y											1.0	.77	.55	.21	.03	-	.04
12. TR-Y												1.0	.72	.24	.02	-	.03
13. UA-Y													1.0	.58	.27	-	.32
14. LA-Y														1.0	.88	-	.83
15. HD-Y															1.0	-	-
16. F-X																1.0	-
17. F-Y																	1.0

(Probability for significance, 960 cases: .05 = .09;   .01 = .12;   .001 = .15)

(A dash in the matrix signifies that a correlational test was not conducted)

nonsignificant (Type I error) was .116. This could also be called the error rate per matrix. Stated another way, 123 correlational comparisons could lead to fourteen Type I errors by chance (Kirk, 1968). One other rule used in matrix comparison was: if two correlations were statistically different but highly significant within their sample at the .001 level (r = .15) and were in the same direction, the deviation was ignored.

The comparisons indicated that both sets of matrices were similar, and therefore, could be combined. Using the Fisher Z criterion, there were 23 and 11 deviations, respectively, for the floor-knuckle (F-K) and knuckle-shoulder (K-S) lift data. By considering the second criterion of correlational significance beyond .001 these deviations dropped to eleven (F-K) and eight (K-S) in the two regimes. After accounting for the items that could occur by chance, the number of actual deviations were not thought to be sufficient to prevent combining the data. In addition, there are many more checks on data validity in the investigation.

The second series of analyses involved two sets of stepwise regression . The following calculations were performed with the inertial force patterns at the hands being used as the criterion variables:

(1) predictor variables were the peak forces of the platform and the integrated EMG's of the two muscles (Tables 11 to 14).

(2) segment accelerations in the x and y planes were the predictors (Tables 15 to 18).

The computer package, BMD 02R (Dixon, 1974), used in these tests selected those variables which when combined had the highest predictive power with the criterion. Each of the eight Tables contained three separate calculations, one for each sample (experimental, validation, combined). The beta weights from the experimental sample were used in the analysis of the validation group for each of the lifts. As can be seen from the Tables, all multiple correlations were highly significant. With the results being cross-validated, the data were combined and the statistics computed again. The combined group's

TABLE 11

STEPWISE REGRESSION PREDICTING INERTIAL FORCE IN THE Y-AXIS AT THE HAND USING

FORCE PLATFORM AND ELECTROMYOGRAM VARIABLES AS PREDICTORS

(FLOOR—KNUCKLE LIFT)

VARIABLE ENTERED	EXPERIMENTAL GROUP				VALIDATION GROUP				COMBINED GROUPS			
	R(1)	r(2)	WT(3)	%VAR(4)	R	r	WT.	%VAR	R	r	WT.	%VAR.
Sagittal Plane (Platform)	.438	-.438	-.31	13.5	.278	-.278	-.31	8.6	.353	-.353	-.28	9.9
Transverse Plane (Platform)	.530	.448	.32	14.3	.346	.105	.32	3.4	.396	.285	.17	4.8
Quadriceps Femoris (EMG)	.537	.139	.07	1.0	.368	.234	.07	1.6	.414	.192	.13	2.5
Final F (df = 3,476 or 956)	63.3 (p $\leq$ .01)				24.4 (p $<$ .01)				65.9 (p $\leq$ .01)			

TABLE 12

STEPWISE REGRESSION PREDICTING INERTIAL FORCE IN X-AXIS AT THE HAND USING

FORCE PLATFORM AND ELECTROMYOGRAM VARIABLES AS PREDICTORS

(FLOOR—KNUCKLE LIFT)

VARIABLE ENTERED	EXPERIMENTAL GROUP				VALIDATION GROUP				COMBINED GROUPS			
	R(1)	r(2)	WT(3)	%VAR(4)	R	r	WT.	%VAR.	R	r	WT.	%VAR.
Transverse Plane (Platform)	.680	.680	.67	45.6	.580	.580	.67	38.9	.628	.628	.62	38.7
Quadriceps Femoris (EMG)	.681	.142	.06	0.8	.634	.216	.06	1.3	.632	.182	.07	1.3
Final F (df = 2,477 or 957)	206.8 (p $\leq$ .01)				160.3 (p $<$ .01)				318.3 (p $\leq$ .01)			

(1) Cumulative Multiple R, corrected for shrinkage.

(2) Product Moment correlation with criterion.

(3) Beta Weights used in final equation.

(4) Explained variance in percentage for each variable in final equation (r)(beta Wt.) = %Var. %Var. = R^2

TABLE 13

STEPWISE REGRESSION PREDICTING INERTIAL FORCE IN THE Y-AXIS AT THE HAND USING

FORCE PLATFORM AND ELECTROMYOGRAM VARIABLES AS PREDICTORS

(KNUCKLE-SHOULDER LIFT)

VARIABLE ENTERED	EXPERIMENTAL GROUP				VALIDATION GROUP				COMBINED GROUPS			
	R(1)	r(2)	WT(3)	%VAR(4)	R	r	WT.	%VAR.	R	r	WT.	%VAR.
Transverse Plane (Platform)	.407	.407	.40	16.3	.474	.474	.40	19.0	.441	.441	.41	18.1
Coronal Plane (Platform)	.410	.161	.06	1.0	.435	.237	.06	1.4	.449	.199	.07	1.4
Sagittal Plane (Platform)	.411	.092	-.04	-.4	.442	.295	-.03	-.9	.450	.188	.04	.8
Final F (df = 3,476 or 956)	31.9 (p $\leq$ .01)				38.5 (p $\leq$ .01)				80.9 (p $\leq$ .01)			

TABLE 14

STEPWISE REGRESSION PREDICTING INERTIAL FORCE IN X-AXIS AT THE HAND USING

FORCE PLATFORM AND ELECTROMYOGRAM VARIABLES AS PREDICTORS

(KNUCKLE-SHOULDER LIFT)

VARIABLE ENTERED	EXPERIMENTAL GROUP				VALIDATION GROUP				COMBINED GROUPS			
	R(1)	r(2)	WT(3)	%VAR(4)	R	r	WT.	%VAR.	R	r	WT.	%VAR.
Transverse Plane (Platform)	.235	.235	.10	2.3	.363	.363	.10	3.6	.298	.298	.22	6.7
Sagittal Plane (Platform)	.369	.347	.31	10.7	.344	.145	.31	4.5	.350	.271	.18	4.9
Deltoid Electromyogram	.409	.204	.18	3.7	.318	.112	.18	2.0	.373	.164	.14	2.3
Final F (df = 3,476 or 956)	31.87 (p $\leq$ .01)				14.14 (p $\leq$ .01)				51.5 (p $\leq$ .01)			

(1) Cumulative Multiple R, corrected for shrinkage.

(2) Product Moment correlation with criterion.

(3) Beta Weights used in final equation.

(4) Explained variance in percentage for each variable in final equation (r)(Beta Wt.) = %Var. = R^2.

TABLE 15

STEPWISE REGRESSION PREDICTING INERTIAL FORCE IN Y-AXIS AT THE HAND USING

MOVEMENT VARIABLES AS PREDICTORS (FLOOR-KNUCKLE LIFT)

VARIABLE ENTERED	EXPERIMENTAL GROUP				VALIDATION GROUP				COMBINED GROUPS			
	R(1)	r(2)	WT(3)	%VAR(4)	R	r	WT.	%VAR.	R	r	WT.	%VAR.
Arm Acceleration	.868	.868	1.43	124.0	.867	.867	1.43	124.0	.867	.867	1.19	103.2
Trunk Acceleration	.882	.794	-.58	-46.2	.882	.798	-.58	-46.3	.873	.796	-.34	-27.0
Final F (df = 2,477 or 957)	832.5 (p < .01)				835.5 (p < .01)				1537.7 (p < .01)			

TABLE 16

STEPWISE REGRESSION PREDICTING INERTIAL FORCE IN X-AXIS AT THE HAND USING

MOVEMENT VARIABLES AS PREDICTORS (FLOOR-KNUCKLE LIFT)

VARIABLE ENTERED	EXPERIMENTAL GROUP				VALIDATION GROUP				COMBINED GROUPS			
	R(1)	r(2)	WT(3)	%VAR(4)	R	r	WT.	%VAR.	R	r	WT.	%VAR.
Arm Acceleration	.872	.872	1.07	93.2	.830	.830	1.07	88.8	.852	.852	1.01	86.1
Trunk Acceleration	.888	.549	-.26	-14.4	.875	.471	-.26	-12.2	.865	.511	-.22	-11.2
Final F (df = 2,477 or 957)	892.4 (p < .01)				779.1 (p < .01)				1425.7 (p < .01)			

(1) Cumulative Multiple R, corrected for shrinkage.

(2) Product Moment correlation with criterion.

(3) Beta Weights used in final equation.

(4) Explained variance in percentage for each variable in final equation (r)(Beta Wt.) = % Var. = R^2.

TABLE 17

STEPWISE REGRESSION PREDICTING INERTIAL FORCE IN Y-AXIS AT THE HAND USING

MOVEMENT VARIABLES AS PREDICTORS (KNUCKLE-SHOULDER LIFT)

VARIABLE ENTERED	EXPERIMENTAL GROUP				VALIDATION GROUP				COMBINED GROUPS			
	R(1)	r(2)	WT(3)	%VAR(4)	R	r	WT.	%VAR.	R	r	WT.	%VAR.
Lower Arm Acceleration	.852	.852	.94	80.1	.800	.800	.94	75.2	.826	.826	.97	80.1
Upper Arm Acceleration	.859	.429	-.15	-6.4	.849	.221	-.15	-3.3	.850	.320	-.24	-7.7
Final F (df = 2,477 or 957)	669.5 (p ≤ .01)				615.7 (p ≤ .01)				1241.3 (p ≤ .01)			

TABLE 18

STEPWISE REGRESSION PREDICTING INERTIAL FORCE IN X-AXIS AT THE HAND USING

MOVEMENT VARIABLES AS PREDICTORS (KNUCKLE-SHOULDER LIFT)

VARIABLE ENTERED	EXPERIMENTAL GROUP				VALIDATION GROUP				COMBINED GROUPS			
	R(1)	r(2)	WT(3)	%VAR(4)	R	r	WT.	%VAR.	R	r	WT.	%VAR.
Lower Arm Acceleration	.798	.798	1.22	97.4	.824	.824	1.22	100.5	.811	.811	1.27	103.0
Upper Arm Acceleration	.843	.507	-.79	-40.1	.848	.589	-.79	-46.5	.859	.548	-.91	-49.9
Trunk Acceleration	.849	.445	.51	22.7	.856	.565	.51	28.8	.867	.557	.57	31.7
Leg Acceleration	.855	.332	-.21	-6.9	.863	.398	-.21	-8.4	.872	.397	-.22	-8.7
Final F (df = 4,475 or 955)	322.7 (p ≤ .01)				346.5 (p ≤ .01)				765.8 (p ≤ .01)			

(1) Cumulative Multiple R, corrected for shrinkage.

(2) Product Moment correlation with criterion.

(3) Beta Weights used in final equation.

(4) Explained variance in percentage for each variable in final equation (r)(Beta Wt.) = % Var. = R^2.

multiple correlations (corrected for shrinkage), pertaining to the
force platform and electromyograms, were all highly significant with
the lowest and highest correlations being, respectively, .373 (x axis,
knuckle-shoulder) and .632 (x axis, floor-knuckle). The highest
product-moment correlations in both lifts were the sagittal and
transverse peak forces. The prediction equations produced by these
analyses are:

Floor-Knuckle

F-Y = .561 + 2.492 (QUAD) - .184 (SAG) + .029 (TRANS)
(standard error of estimate = 3.81, R = .414)

F-X = .405 + 1.815 (QUAD) + .137 (TRANS)
(standard error of estimate = 4.29, R = .632)

Knuckle-Shoulder

F-Y = -.281 + .024 (SAG) + .083 (COR) + .088 (TRANS)
(standard error of estimate = 1.97, R = .450)

F-X = -.044 + 1.810 (DEL) + .104 (SAG) + .045 (TRANS)
(standard error of estimate = 1.90, R = .373)

These relationships are more significant when it is realized that
the forces at the feet and hands are not the same constructs. Grieve
(1974) viewed the body as a concentrated mass located at the center of
gravity having two force elements - upper and lower. The upper
element force was measured at the hands, and moved with a velocity
equal to the difference between the computed velocities of the load
and the center of gravity of the body. The lower force was concen-
trated at the feet, and its velocity was equal to the computed
velocity of the center of gravity.

The computations involving the ac ation variables were all
highly significant with the corre. us, rrected for shrinkage,
ranging from .850 to .873. Accelerations at the hands were not used
in these analyses. In general, the major predictor in each lift was
the lower arm (K-S) and arm (F-K) accelerations. The resulting
equations are as follows:

Floor-Knuckle

F-Y = .637 + .015 (ARM-Y) - .008 (TR-Y)
(standard error of estimate = 2.04, R = .873)

F-X = - .013 + .017 (ARM-X) - .013 (TR-X)

    (standard error of estimate = 2.77, R = .865)

Knuckle-Shoulder

F-Y = .126 + .027 (LA-Y) - .013 (UA-Y)

    (standard error of estimate = 1.16, R= .850)

F-X = - .042 - .029 (LEG-X) + .028 (TR-X) - .025 (UA-X) +
    .029 (LA-X)

    (standard error of estimate = 1.00, R = .872)

The final multivariate technique to be discussed is factor analysis. Cattell (1966) outlined a conceptual model for factor analysis that involved alternating the emphasis of the investigation between three dimensions: people, conditions, and time. According to Cattell's model the methodology used in the present research can be called the "P" technique. As seen from the data box, the testing conditions are treated as variables, the time segments as cases and people as constants. In this approach, the resultant factors are clusters of variables as they covary over time.

Separate analyses were performed on both lift regimes. The principal axis method was conducted using the BMD package, BMD 08 M, at the Texas Tech Computer Center (Dixon, 1974). This method operates to maximize the amount of variance shared commonly among the factors. Factoring was halted when the Eigenvalue slipped below 1.0. Accordingly, two factors explaining 58% of the variance and three factors with 53% communality resulted, respectively, for the floor to knuckle and knuckle to shoulder lifts.

Varimax rotation was performed so that each variable loaded mainly on only one factor. In this way, factorial interpretation is as simple as possible. Tables 19 and 20 contain the results of the statistical rotation with the variable loadings outlined by factor and group. In the floor-knuckle lifts, factor I was represented by movement in the x axis, while factor II was defined by changes in the y axis. Factor III in the knuckle-shoulder regime stood for x axis movement. Trunk/upper arm/leg and lower arm/hand movements in the y axis, respectively, defined factors IV and V.

TABLE 19

FACTOR MATRIX AND LOADINGS FOR FLOOR—KNUCKLE LIFT

VARIABLES	EXPERIMENTAL GROUP FACTORS			VALIDATION GROUP FACTORS			COMBINED GROUP FACTORS		
	I	II	h^2	I	II	h^2	I	II	h^2
1. Quadriceps Femoris	.16	+.05	.03	.24	+.13	.07	.20	+.11	.05
2. Deltoid	.13	-.03	.02	.02	-.03	.00	.08	-.02	.01
3. Sagittal Plane	-.29	-.37	.22	-.43	-.09	.19	-.34	-.22	.16
4. Coronal Plane	.36	+.07	.13	.24	-.06	.06	.29	+.03	.09
5. Transverse Plane	.85	+.05	.73	.73	-.19	.57	.78	-.04	.61
6. Lower Leg – X	.85	+.32	.82	.73	+.41	.70	.76	+.42	.75
7. Upper Leg – X	-.83	-.20	.73	-.69	-.11	.49	-.73	-.19	.57
8. Trunk – X	.44	-.77	.79	.41	-.54	.46	.46	-.60	.57
9. Arm – X	.91	-.35	.95	.93	-.19	.90	.94	-.20	.92
10. Hand – X	.96	-.18	.95	.96	-.04	.92	.96	-.04	.92
11. Lower Leg – Y	-.20	+.64	.45	-.18	+.73	.57	-.23	+.67	.50
12. Upper Leg – Y	-.01	+.88	.77	-.07	+.85	.73	-.10	+.84	.72
13. Trunk – Y	.45	+.88	.98	.27	+.95	.98	.29	+.95	.99
14. Arm – Y	.60	+.74	.91	.43	+.86	.92	.45	+.85	.93
15. Hand – Y	.68	+.64	.87	.50	+.79	.87	.53	+.77	.87
SUM OF SQUARED LOADINGS	5.40	3.95	9.35	4.33	4.10	8.43	4.61	4.05	8.66
AVERAGE (Proportion Total) Variance	.36	.26	.62	.29	.27	.56	.31	.27	.58

TABLE 20

FACTOR MATRIX AND LOADINGS FOR KNUCKLE-SHOULDER LIFT

VARIABLES	EXPERIMENTAL GROUP FACTORS				VALIDATION GROUP FACTORS				COMBINED GROUP FACTORS			
	III	IV	V	h²	III	IV	V	h²	III	IV	V	h²
1. Quadriceps Femoris	.04	.02	-.01	.00	.15	-.06	.01	.03	.09	.00	.00	.01
2. Deltoid	.24	.01	-.01	.06	.14	+.07	.03	.03	.20	.02	.01	.04
3. Sagittal Plane	.30	-.03	.14	.11	.04	-.07	.46	.22	.21	-.06	.24	.11
4. Coronal Plane	-.22	-.27	.23	.17	-.06	-.16	.40	.19	-.16	-.22	.28	.15
5. Transverse Plane	.20	-.06	.47	.26	.31	-.13	.61	.49	.22	-.09	.53	.34
6. Leg - X	.72	-.13	.02	.54	.70	+.09	-.02	.50	.70	-.06	.06	.50
7. Trunk - X	.96	.00	.05	.92	.89	+.12	.10	.82	.94	.03	.11	.89
8. Upper Arm - X	.90	.10	.02	.82	.85	+.07	.04	.73	.88	.08	.06	.78
9. Lower Arm - X	.92	-.03	.05	.85	.90	-.01	.07	.82	.91	-.03	.08	.84
10. Hand - X	.66	-.16	.14	.48	.61	-.05	.20	.41	.63	-.13	.18	.45
11. Leg - Y	-.02	.80	.03	.64	.06	+.70	-.08	.50	.00	.75	-.03	.56
12. Trunk - Y	.02	.90	.05	.81	-.02	+.98	-.14	.98	.02	.93	-.09	.87
13. Upper Arm - Y	-.23	.76	.30	.72	.03	+.88	.13	.79	-.13	.80	.25	.72
14. Lower Arm - Y	-.03	.30	.92	.94	.16	+.52	.77	.89	.02	.38	.89	.93
15. Hand - Y	.07	-.01	.89	.80	.15	+.31	.82	.79	.07	.11	.90	.83
SUM OF SQUARED LOADINGS	3.82	2.25	2.05	8.12	3.39	2.68	2.12	8.19	3.56	2.31	2.15	8.02
AVERAGE (Proportion Total) Variance	.25	.15	.14	.54	.23	.18	.14	.55	.24	.15	.14	.53

Some principles concerning the properties of factor loadings will now be presented. A factor loading is similar to a correlation coefficient. The square of the loading indicates the amount of variance explained by a variable on a factor. The sum of the squares in any column gives the total amount of variance by a factor, while the average of these squared loadings depicts the proportion of total variance. The sum of squared loadings in a row (h^2) shows the proportion of variance by a variable on all of the factors. The higher the h^2, the more common variance a variable shares with the other variables (Nunnally, 1967).

The remaining step, prior to utilizing the factor-variables in the forthcoming analyses, is to compare the factor structure in both the experimental and validation samples. Nunnally (1967) claimed that the proper method of factor comparison is to use factor scores from two different analyses. This can be accomplished if the same people are involved in both factor structures. Since this was the case, the factor scores for each person in two data sets were correlated and the comparability of the factors were judged by the size of the relationships. The mean factor scores in the "pre" and "post" condition ($N = 32$) for each subject in either replication (experimental and validation) and combined group were correlated using the Spearman Rank Correlation Coefficient (Siegel, 1956). This coefficient closely approximates the product-moment correlation in samples larger than 30. This test involves ranking the subjects in both groups and squaring the subtracted difference (d). The correlation then is computed using the following formula ($N = 32$):

$$r = 1 - \frac{6 \text{ (sum of squared differences)}}{N^3 - N}$$

The results indicated a high similarity between both factor structures, and gave support to the validity of the loadings used in the combined sample. The following correlations by factor and significance level can be shown below:

Factor	Correlation	Probability Level
I	.751	.001
II	.911	.001
III	.360	.05
IV	.685	.001
V	.915	.001

In summary, the analyses so far have a good deal of predictive and concurrent validity. Using a two group replication approach, the correlation, regression and factor analytic results appear to have been cross-validated. The product of these efforts were:

(1) four equations (2 axes, 2 lifts) using force platform and electromyogram data to predict inertial forces at the hands.

(2) four equations relating bodily acceleration patterns and inertial forces at the hands.

(3) a five-factor model or construct of motion describing two different types of lifts.

Analysis of Variance

Five split-plot analysis of variance (SPF 22·532 and SPF 222·532) tests of the five factors were performed on each of the replication groups (experimental, validation, combined) in each regime. The Texas Tech Computer Center's SAS-76 package for ANOVA (Barr et al, 1976) was utilized in the analyses. The dependent variables were the five factor-variables determined from multivariate statistics in the previous sub-section. The resulting factor scores for each factor were the data studied in the computations. The factor score for each case was found by adding the products of the loadings and standard scores on each of the fifteen variables. The result was a score for every case on the one factor extracted. A case was equal to a specific subject, trial and combination of the following independent variables: sex (A), time (B), program (C), weight (D), measure (E), group (F). In all, there were 960 cases. A high positive factor score indicated that a case related highly with a factor, while the reverse was true for a high negative score (Lawlis and Chatfield, 1974).

The following three levels of testing were conducted in these analyses:

(1) the effects of the independent variables upon the five factor-variables of the experimental, validation and combined groups (Tables 21 - 25).

(2) simple main effects tests to study further the significant interactions (Table 26 - 29).

(3) Tukey tests to compare means among levels of the significant main or simple main effects (Tables 30 - 33).

Care was taken during these analyses to avoid both Types I and II errors. Type II error (determination of non-significance when in fact significant) was kept small by making the preliminary tests on each replication (experimental, validation) at an "alpha" level of .25 (Winer, 1971). Also to be significant, a main effect or interaction had to be beyond the "alpha" level for the combined group's ANOVA. In other words, these levels changed as the level of testing changed (.25 for experimental and validation, while .1 for combined). Type I error (rejection of the null hypothesis when it is true) was partially controlled by varying the levels of significance with the number of observations tested. The procedure recommended by Kirk (1968) was to assign the same error rate to the simple main-effects tests as that given to the overall F-ratio. The various comparison tests among means were treated similarly. The following equation, therefore, was used to set the "alpha" level at the various stages of testing: .1/number of observations = alpha. The use of replication groups and changes in the levels of significance as the analysis progressed should have increased experimental validity. The initial willingness to commit a Type I vice a Type II error hopefully insured that all avenues of possible scrutiny were included in the data pool. As the testing advanced, the use of more stringent levels of significance should have helped to curtail Type I error.

Tables 21 to 25 contain the ANOVA results from each factor on the three samples. Each factor-variable is signified by:

Factor I - movement in x axis, floor-knuckle lift (F-K)

Factor II - movement in y axis, floor-knuckle lift

Factor III - movement in x axis, knuckle-shoulder lift (K-S)

Factor IV - movement of leg, trunk and upper arm segments in
y axis, knuckle-shoulder lift

Factor V - movement of lower arm and hand segments in y axis,
knuckle-shoulder lift

Pooling procedures were used in this part of the investigation. All
sources of interaction that were not of interest to the experimenter
or did not contribute significantly to the total variation became part
of the error term. The use of both replication groups to determine
the final model in the combined group analysis was very similar to the
"middle-of-the-road" position concerning pooling taken by Winer (1971)
and Kirk (1968). Also, replication interactions were pooled into the
error term (Winer, 1971).

An examination of these five Tables shows that the results contain
some F ratios of less than 1.0. This could be the result of chance but
it could also be caused by a failure to meet some of the assumptions of
the fixed-effects linear model. However, since the F distribution is
robust with respect to moderate deviations of normality and of homo-
geneity of error variance, the magnitude of Type I error should not be
greatly influenced (Kirk, 1968; Winer, 1971). Failure to meet these
assumptions can affect the sensitivity and the significance level of
the test (Cochran and Cox, 1957). However, the care taken to avoid
experimental error, the large sample size and the ANOVA's function of
serving only as a screening device were strategies purposely used in
this investigation to avoid some of these pitfalls.

Tables 26 to 29 depict the next level of analyses, which were
simple effects tests. Those interactions deemed significant by the
first series of ANOVA's were now further scrutinized. These inter-
actions were time/weight (BD) for factors I, IV, V; sex/time (AB) for
factors II, IV, V; sex/weight (AD) for factor V; and time/program/
measure (BCE) for factors II, V. These tables are labeled as
"incomplete" because only the pertinent information are contained in
them. The levels of significance varied with the number of observa-
tions per interaction. The following probability levels were used in
these analyses:

.05 - B at a, D at a

TABLE 21

ANALYSIS OF VARIANCE (SPF 2, 2, 2 · 5, 3, 2 design) FOR X-AXIS ACCELERATIONS OF BODILY SEGMENTS DURING FLOOR-KNUCKLE LIFT (FACTOR I)

SOURCE OF VARIATION	EXPERIMENTAL GROUP				VALIDATION GROUP				COMBINED GROUPS			
	DF	SS	MS	F(p)	DF	SS	MS	F(p)	DF	SS	MS	F(p)
BET. SUBJ.(IND. DIFF.)	15	2.52	.17	2.78(.01)	15	1.19	.08	.59	31	3.30	.11	.98
A (SEX)	1	.32	.32	2.02	1	.15	.15	1.89	1	.23	.23	2.15
C (PROGRAM)	1	.14	.14	.88	1	.01	.01	.13	1	.02	.02	.19
F (GROUP)	-	-	-	-	-	-	-	-	1	.06	.06	.56
ERROR (SUBJ IN GRPS)	13	2.06	.16	-	13	1.03	.08	-	28	2.99	.11	-
WITHIN SUBJECTS	464	480.29	-	-	464	503.61	-	-	928	991.91	-	-
B (TIME)	4	448.65	112.2	1859.5(.01)	4	438.56	109.64	812.56(.01)	4	888.39	222.10	2051.2(.01)
D (WEIGHT)	2	.11	.06	.91	2	.02	.01	.07	2	.09	.05	.42
E (MEASURE)	1	.43	.43	7.13(.01)	1	0.0	0.0	0.0	1	.12	.12	1.10
CE	1	.18	.18	2.98(.10)	1	.02	.02	.15	1	.05	.05	.46
BD	8	.83	.11	1.72(.10)	8	4.22	.53	3.91(.01)	8	2.54	.32	2.93(.01)
BE	4	1.75	.44	7.25(.01)	4	.82	.21	1.52(.25)	4	1.98	.50	4.57(.01)
BCE	4	1.80	.45	7.46(.01)	4	.60	.15	1.11	4	.86	.22	1.99(.10)
ERR (POOL IN SUBJS)	440	26.54	.06	-	440	59.37	.14	-	904	97.88	.11	-
TOTAL	479	482.81	-	-	479	504.80	-	-	959	995.21	-	-

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TABLE 22

ANALYSIS OF VARIANCE (SPF 2, 2, 2 · 5, 3, 2 design) FOR Y-AXIS ACCELERATIONS OF BODILY SEGMENTS DURING FLOOR-KNUCKLE LIFT (FACTOR II)

SOURCE OF VARIATION	EXPERIMENTAL GROUP				VALIDATION GROUP				COMBINED GROUPS			
	DF	SS	MS	F(p)	DF	SS	MS	F(p)	DF	SS	MS	F(p)
BET. SUBJ.(IND. DIFF.)	15	11.75	.78	5.81(.01)	15	13.19	.88	3.23(.01)	31	22.08	.71	3.06(.01)
A (SEX)	1	.01	.01	.02	1	2.27	2.27	2.91(.10)	1	.32	.32	.47
C (PROGRAM)	1	3.70	3.70	5.98(.05)	1	.78	.78	1.0	1	2.67	2.67	3.96(.10)
F (GROUP)	-	-	-	-	-	-	-	-	1	.19	.19	.28
ERROR (SUBJS IN GRPS)	13	8.04	.62	-	13	10.14	.78	-	28	18.90	.68	-
WITHIN SUBJECTS	464 480.42		-	-	464 489.10		-	-	928 966.37		-	-
B (TIME)	4	395.92	98.98	733.57(.01)	4	351.92	87.98	323.06(.01)	4	733.62	183.41	790.70(.01)
D (WEIGHT)	2	.17	.09	.67	2	.26	.13	.48	2	.27	.14	.60
E (MEASURE)	1	.73	.73	5.41(.05)	1	.08	.08	.29	1	1.01	1.01	4.35(.05)
CE	1	.47	.47	3.48(.10)	1	.13	.13	.48	1	.74	.74	3.19(.10)
AD	2	.08	.04	.30	2	.20	.10	.37	2	1.27	.64	2.76(.10)
AB	4	1.77	.44	3.26(.05)	4	6.88	1.72	6.32(.01)	4	4.35	1.09	4.69(.01)
BD	8	1.25	.16	1.19	8	4.59	.57	2.09(.05)	8	5.82	.73	3.15(.01)
BC	4	7.42	1.86	13.78(.01)	4	3.29	.82	3.01(.05)	4	6.16	1.54	6.64(.01)
BE	4	7.61	1.90	14.08(.01)	4	2.71	.53	1.95(.10)	4	2.48	.62	2.67(.05)
CEB	4	6.98	1.75	12.97(.01)	4	3.04	.76	2.79(.05)	4	1.94	.49	2.11(.10)
DCE	2	.27	.14	1.04	2	.04	.02	.07	2	1.81	.91	3.92(.05)
ERR (POOL IN SUBJS)	428	57.75	.13	-	428	116.56	.272	-	892	206.90	.23	-
TOTAL	479	492.17	-	-	479	502.29	-	-	959	988.45	-	-

TABLE 23

ANALYSIS OF VARIANCE (SPF 2, 2, 2 · 5, 3, 2) FOR X-AXIS ACCELERATIONS OF BODILY SEGMENTS

DURING KNUCKLE-SHOULDER LIFT (FACTOR III)

SOURCE OF VARIATION	EXPERIMENTAL GROUP				VALIDATION GROUP				COMBINED GROUPS			
	DF	SS	MS	F(p)	DF	SS	MS	F(p)	DF	SS	MS	F(p)
BET. SUBJ. (IND. DIFF)	15	79.31	5.29	4.89(.01)	15	.53	.04	.55	31	10.28	.33	1.98(.01)
A (SEX)	1	7.67	7.67	3.94(.10)	1	0.0	0.0	0.0	1	.02	.02	.06
C (PROGRAM)	1	14.62	14.62	7.52(.05)	1	.03	.03	.72	1	.01	.01	.03
F (GROUP)	-	-	-	-	-	-	-	-	1	.16	.16	.46
AC	1	33.68	33.68	17.32(.01)	1	0.0	0.0	0.0	1	.35	.35	1.00
ERROR (SUBJ IN GRPS)	12	23.34	1.95	-	12	.50	.04	-	28	9.74	.35	-
WITHIN SUBJECTS	464	546.06	-	-	464	32.70	-	-	928	169.74	-	-
B (TIME)	4	16.35	4.09	3.78(.01)	4	.35	.09	1.36(.25)	4	7.0	1.75	10.43(.01)
D (WEIGHT)	2	.67	.34	.31	2	.71	.36	5.53(.01)	2	.13	.06	.39
E (MEASURE)	1	2.43	2.43	2.25(.25)	1	.70	.70	10.90(.01)	1	.24	.24	1.43
CE	1	1.86	1.86	1.72(.10)	1	.11	.11	1.71(.25)	1	0.0	0.0	0.0
AB	4	8.50	2.13	1.97(.10)	4	.03	.01	.12	4	3.24	.81	4.83(.01)
BC	4	31.13	7.78	7.20(.01)	4	1.80	.45	7.01(.01)	4	2.58	.64	3.85(.01)
AE	1	3.23	3.23	2.99(.10)	1	.05	.05	.78	1	.64	.64	3.82(.05)
BCE	4	2.92	.73	.68	4	.51	.13	1.99(.10)	4	3.80	.95	5.66(.01)
ERR (POOL IN SUBJS)	443	478.97	1.08	-	443	28.44	.06	-	907	152.11	.17	-
TOTAL	479	625.37	-	-	479	33.23	-	-	959	180.02	-	-

TABLE 24

ANALYSIS OF VARIANCE (SPF 2, 2, 2 · 5, 3, 2 design) FOR Y-AXIS ACCELERATIONS OF LEG, TRUNK AND UPPER ARM SEGMENTS DURING KNUCKLE-SHOULDER LIFT (FACTOR IV)

SOURCE OF VARIATION	EXPERIMENTAL GROUP				VALIDATION GROUP				COMBINED GROUPS			
	DF	SS	MS	F(p)	DF	SS	MS	F(p)	DF	SS	MS	F(p)
BET. SUBJ. (IND. DIFF.)	15	26.64	1.78	2.46(.01)	15	8.49	.57	6.07(.01)	31	19.68	.63	3.55(.01)
A (SEX)	1	.57	.57	2.08(.25)	1	.27	.27	.81	1	1.19	1.19	3.12(.10)
C (PROGRAM)	1	11.35	11.35	41.40(.01)	1	1.06	1.06	3.19(.10)	1	2.30	2.30	6.03(.05)
F (GROUP)	-	-	-	-	-	-	-	-	1	.14	.14	.37
AC	1	11.43	11.43	41.69(.01)	1	3.17	3.17	9.53(.01)	1	5.76	5.76	15.11(.01)
ERROR (SUBJ IN GRPS)	12	3.29	.27	-	12	3.99	.33	-	27	10.29	.38	-
WITHIN SUBJECTS	464	410.10	-	-	464	50.67	-	-	928	201.68	-	-
B (TIME)	4	11.23	2.81	3.89(.01)	4	.89	.22	2.39(.05)	4	7.68	1.92	10.74(.01)
D (WEIGHT)	2	.97	.49	.67	2	.36.	.18	1.93(.25)	2	2.45	1.22	6.85(.01)
E (MEASURE)	1	5.75	5.75	7.98(.01)	1	.01	.01	.11	1	.93	.93	5.20(.05)
CE	1	6.27	6.27	8.70(.01)	1	0.0	0.0	0.0	1	.76	.76	4.25(.05)
AD	2	1.21	.61	.84	2	.73	.37	3.92(.05)	2	2.16	1.08	6.04(.01)
AB	4	5.50	1.38	1.91(.25)	4	1.33	.33	3.57(.01)	4	2.43	.61	3.40(.01)
BD	8	7.99	1.00	1.39(.25)	8	2.25	.28	3.02(.01)	8	7.62	.95	5.33(.01)
CD	2	25.01	12.51	17.35(.01)	2	3.52	1.76	18.88(.01)	2	10.69	5.35	29.90(.01)
BC	4	11.71	2.93	4.06(.01)	4	.91	.23	2.44(.05)	4	2.82	.70	3.94(.01)
BE	4	13.20	3.30	4.58(.01)	4	.48	.12	1.29	4	2.67	.67	3.73(.01)
BCE	4	12.73	3.18	4.41(.01)	4	.29	.07	.78	4	2.01	.50	2.81(.05)
ERR (POOL IN SUBJ)	428	308.53	.72	-	428	39.90	.09	-	892	159.46	.18	-
TOTAL	479	436.74	-	-	479	59.16	-	-	959	221.36	-	-

TABLE 25

ANALYSIS OF VARIANCE (SPF 2, 2, 2 · 5, 3, 2 design) FOR Y-AXIS ACCELERATIONS OF LOWER ARM AND
HAND SEGMENTS DURING KNUCKLE-SHOULDER LIFT (FACTOR V)

SOURCE OF VARIATION	EXPERIMENTAL GROUP				VALIDATION GROUP				COMBINED GROUPS			
	DF	SS	MS	F(p)	DF	SS	MS	F(p)	DF	SS	MS	F(p)
BET. SUBJ.(IND. DIFF.)	15	4.21	.28	1.65(.10)	15	11.14	.74	3.97(.01)	31	14.29	.46	2.37(.01)
A (SEX)	1	.28	.28	3.20(.10)	1	.99	.99	1.27	1	1.18	1.18	2.95(.10)
C (PROGRAM)	1	1.07	1.07	12.23(.01)	1	.37	.37	.47	1	.01	.01	.03
F (GROUP)	-	-	-	-	-	-	-	-	1	.09	.09	.23
AC	1	1.81	1.81	20.69(.01)	1	.42	.42	.54	1	2.21	2.21	5.53(.05)
ERROR (SUBJ IN GRPS)	12	1.05	.09	-	12	9.36	.78	-	27	10.80	.40	-
WITHIN SUBJECTS	464	457.86	-	-	464	449.22	-	-	928	882.70	-	-
B (TIME)	4	352.49	88.12	517.23(.01)	4	346.19	86.55	462.22(.01)	4	671.99	168.0	864.11(.01)
D (WEIGHT)	2	2.81	1.41	8.25(.01)	2	1.18	.59	3.15(.05)	2	2.38	1.19	6.12(.01)
E (MEASURE)	1	1.27	1.27	7.45(.01)	1	.57	.57	3.04(.10)	1	1.55	1.55	7.97(.01)
CE	1	1.45	1.45	8.51(.01)	1	.53	.53	2.83(.10)	1	1.51	1.51	7.77(.01)
AD	2	2.70	1.35	7.92(.01)	2	.58	.29	1.55(.25)	2	1.62	.81	4.17(.05)
AB	4	8.48	2.12	12.44(.01)	4	.77	.19	1.03	4	5.93	1.48	7.63(.01)
BD	8	6.79	.85	4.98(.01)	8	10.03	1.25	6.70(.01)	8	10.46	1.31	6.73(.01)
CD	2	2.02	1.01	5.93(.01)	2	3.86	1.93	10.31(.01)	2	6.89	3.44	17.72(.01)
BC	4	2.84	.71	4.17(.01)	4	2.55	.64	3.40(.01)	4	1.69	.42	2.17(.10)
BE	4	1.44	.36	2.11(.10)	4	1.11	.28	1.48(.25)	4	1.71	.43	2.20(.10)
BCE	4	2.65	.66	3.89(.01)	4	1.71	.43	2.28(.10)	4	3.55	.89	4.56(.01)
ERR (POOL IN SUBJS)	428	72.92	.17	-	428	80.14	.19	-	892	173.42	.19	-
TOTAL	479	462.07	-	-	479	460.36	-	-	959	896.99	-	-

TABLE 26

ANALYSIS OF VARIANCE FOR SIMPLE EFFECTS (INCOMPLETE TABLE) OF THE

COMBINED GROUP'S BD INTERACTION (FACTORS I, IV, V)

SOURCE OF VARIATION	FACTOR I				FACTOR IV				FACTOR V			
	df	SS	MS	F(p)	df	SS	MS	F(p)	df	SS	MS	F(p)
BETWEEN SUBJECTS	31	3.30	-	-	31	19.68	-	-	31	14.29	-	-
WITHIN SUBJECTS	928	991.91	-	-	928	201.68	-	-	928	882.70	-	-
B at d_1 (10 lbs)	4	327.00	81.75	755.03(.01)	4	.71	.18	.99	4	238.77	59.69	307.03(.01)
B at d_2 (25 lbs)	4	296.90	74.23	685.53(.01)	4	.29	.07	.41	4	216.45	54.11	278.33(.01)
B at d_3 (40 lbs)	4	267.04	66.76	616.58(.01)	4	14.29	3.57	19.98(.01)	4	227.23	56.81	292.19(.01)
D at b_1 (Time 1)	2	.64	.32	2.96	2	.25	.13	.70	2	3.51	1.76	9.03(.01)
D at b_2 (Time 2)	2	.09	.05	.42	2	8.80	4.40	24.61(.01)	2	2.24	1.12	5.76(.01)
D at b_3 (Time 3)	2	.63	.32	2.90	2	.13	.06	.36	2	.41	.21	1.05
D at b_4 (Time 4)	2	1.24	.62	5.73(.01)	2	.78	.39	2.18	2	6.67	3.34	17.15(.01)
D at b_5 (Time 5)	2	.04	.02	.18	2	.11	.06	.31	2	.02	.01	.05
ERR (POOL IN SUBJ)	904	97.88	.11	-	892	159.46	.18	-	892	173.42	.19	-
TOTAL	959	995.21	-	-	959	221.36	-	-	959	896.99	-	-

TABLE 27

ANALYSIS OF VARIANCE FOR SIMPLE EFFECTS (INCOMPLETE TABLE) OF THE COMBINED GROUP'S AB INTERACTION (FACTORS II, IV, V)

SOURCE OF VARIATION	FACTOR II				FACTOR IV				FACTOR V			
	df	SS	MS	F(p)	df	SS	MS	F(p)	df	SS	MS	F(p)
BETWEEN SUBJECTS	31	22.08	-	-	31	19.68	-	-	31	14.29	-	-
A at b_1 (Time 1)	1	1.46	1.46	5.95(.02)	1	.14	.14	.76	1	.01	.01	.05
A at b_2 (Time 2)	1	.99	.99	4.03(.05)	1	3.36	3.36	18.19(.01)	1	6.89	6.89	34.37(.01)
A at b_3 (Time 3)	1	2.24	2.24	9.12(.01)	1	.01	.01	.05	1	.02	.02	.10
A at b_4 (Time 4)	1	.01	.01	.04	1	.12	.12	.65	1	.18	.18	.90
A at b_5 (Time 5)	1	0.0	0.0	0.0	1	0.0	0.0	0.0	1	0.0	0.0	0.0
WITHIN CELL POOL ERROR	920	225.80	.25	-	919	169.75	.18	-	919	184.23	.20	-
WITHIN SUBJECTS	928	966.37	-	-	928	201.68	-	-	928	882.70	-	-
B at a_1 (Female)	4	313.00	78.25	337.36(.01)	4	9.30	2.33	13.01(.01)	4	323.38	80.85	415.83(.01)
B at a_2 (Male)	4	424.98	106.25	458.05(.01)	4	.80	.20	1.12	4	354.53	88.63	455.89(.01)
ERROR (POOL IN SUBJS)	892	206.90	.23	-	892	159.46	-	-	892	173.42	.19	-
TOTAL	959	988.45	-	-	959	221.36	-	-	959	896.99	-	-

TABLE 28

ANALYSIS OF VARIANCE FOR SIMPLE EFFECTS (INCOMPLETE TABLE) OF THE COMBINED GROUP'S AD INTERACTION (FACTOR V)

SOURCE OF VARIATION	df	SS	FACTOR V MS	F(p)
BETWEEN SUBJECTS	31	14.29	-	-
A at d_1 (10 lbs)	1	.23	.23	1.15
A at d_2 (25 lbs)	1	.04	.04	.20
A at d_3 (40 lbs)	1	2.53	2.53	12.62(.01)
WITHIN CELL POOL ERROR	919	184.23	.20	-
WITHIN SUBJECTS	928	882.70	-	-
D at a_1 (Female)	2	3.97	1.99	10.21(.01)
D at a_2 (Male)	2	.04	.02	.10
ERROR (Pool in Subjs)	892	173.42	.19	-
TOTAL	959	896.99	-	-

TABLE 29

ANALYSIS OF VARIANCE FOR SIMPLE EFFECTS (INCOMPLETE TABLE) OF THE

COMBINED GROUP'S BCE INTERACTION (FACTORS II, V)

SOURCE OF VARIATION	FACTOR II				FACTOR V			
	df	SS	MS	F(p)	df	SS	MS	F(p)
BETWEEN SUBJECTS	31	22.08	-	-	31	14.29	-	-
WITHIN SUBJECTS	928	966.37	-	-	928	882.70	-	-
CE at b_1 (Time 1)	1	.94	.94	4.05(.05)	1	.33	.33	1.70
CE at b_2 (Time 2)	1	6.51	6.51	28.07(.01)	1	.75	3.86	3.86(.05)
CE at b_3 (Time 3)	1	6.84	6.84	29.49(.01)	1	3.93	3.93	20.21(.01)
CE at b_4 (Time 4)	1	.70	.70	3.02	1	5.00	5.00	25.72(.01)
CE at b_5 (Time 5)	1	.01	.01	.04	1	.01	.01	.05
B at $c_1 e_1$ (Pre/Control)	4	146.50	36.63	157.90(.01)	4	164.15	41.04	211.08(.01)
B at $c_1 e_2$ (Post/Control)	4	187.97	46.99	202.60(.01)	4	149.43	37.36	192.15(.01)
B at $c_2 e_1$ (Pre/trained)	4	158.05	39.51	170.35(.01)	4	145.33	36.33	186.88(.01)
B at $c_2 e_2$ (Post/trained)	4	251.86	62.97	271.46(.01)	4	220.02	55.01	282.92(.01)
ERROR (Pool in Subjs)	892	206.90	.23	-	892	173.42	.19	-
TOTAL	959	988.45	-	-	959	896.99	-	-

.033 - B at d, A at d

.025 - B at ce

.02 - D at b, A at b, CE at b

The error terms depicted in Tables 21 - 25 were "pooled within subjects" and "subjects within groups". In Tables 26 - 29, the "pooled within subjects" error term was the same. However, the "within cell pooled" error was a weighted average of the "pooled within subjects" and "subjects within groups" errors.

The last levels of analysis are shown in Tables 30 to 33. Tukey A Posteriori tests were used to compare the differences between the means of the time treatment and the time/weight, sex/time, sex/weight and time/program/measure interactions. Again, the level of significance was dependent upon .1 (level of overall combined group significance) divided by the number of observations. Since there could have been 6, 8, 15 and 20 observations, respectively, for the AD, AB, BD and BCE interactions, .01 was set as the best approximate level of "alpha" in these tests. The Tukey test statistic is given by Kirk (1968):

$$q = \frac{\text{mean}_1 - \text{mean}_2}{\sqrt{\dfrac{\text{MS of error term}}{\text{cell size}}}}$$

The value of "q" changes with the number of means compared, for example using the .01 level:

2 comparisons (A treatment) = 3.64

3 comparisons (D)   = 4.12

4 comparisons (B, CE)   = 4.40

The time treatment (B) variable (Table 30) accounted for most of the variance of factors I and II in the floor-knuckle lift (F-K) and in factor V of the knuckle-shoulder regime (K-S). These variances (square root = correlation) are determined from equations listed in Kirk (1968). They can be approximated by taking the square root of the sum of squares of the "B" treatment divided by the total sum of squares. The "eta" correlations indicated that the movement patterns for these three factors are curvilinear and closely associated with the time

variable. The motion patterns of each factor shown in Table 30 had the following deviations when the time variable was examined by interaction in Tables 31 to 33:

(1) factor IV, male sex, no differences over the four time comparisons (Table 32).

(2) factor IV, 10 and 25 pound weights, no differences over the four time comparisons (Table 31).

(3) factor V, 40 pound weight, no difference for time comparison between intervals 3 and 4 (Table 31).

Peak acceleration and deceleration movements occurred during the following time intervals:

Factor	Acceleration (upward/backward)	Deceleration (downward/forward)
I (x, F-K)	2	4
II (y, F-K)	1	3
III (x, K-S)	2	3
IV (y, trunk/upper arm/leg, K-S)	3	2
V (y, lower arm/hand, K-S)	1	3

time periods: 1 (0 - .25), 2 (.26 - .50), 3 (.51 - .75), 4 (.76 - 1.00), 5 (1.01 - 1.25)

It is interesting to note that the y axis patterns in both lifts at the arm/hands were the same, while maximum x axis motion occurred one time interval later. Also, there appeared to be a coordinated effort between the y axis movement of the trunk/upper arm (factor IV) and the lower arm/hand (factor V). When the hands were accelerating (between 0 and .50 second) in the knuckle-shoulder regime, the upper arm/trunk demonstrated very little acceleration or was decelerating. A similar observation previously had been discussed by Plagenhoef (1971) in his description of a tennis racket swing. He stated that maximum deceleration of a body segment increased the velocity of the next segment. Maximum deceleration of factor IV at time 2 (.26 - .50 second) coincided very closely with the most stressful portion of lifting the weight, that of passing the load through the horizontal plane.

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Significant sex/time differences are noted in Table 32 for factor
II with males having higher accelerations (time 1: 0 - .25 second) and
decelerations (time 3: .51 - .75 second). Males also had lower decel-
erations at the trunk/upper arms (factor IV) and higher accelerations
at the hands (factor V) during the .26 - .50 second time interval in
the y axis, knuckle-shoulder lift.

The time/weight interaction in Table 31 shows that there were
differences between the 10 and 40 pound lifts (factor I, time 4; factor
IV, time 2; factor V, times 1, 2, 4) and the 25 and 40 pound loads
(factor IV, time 2; factor V, times 1, 4). Table 32 indic es that
most of the deviations in factor V were due to females lifting the 40
pound weight. The AD interaction in factor IV was not studied because
the experimental group (Table 24) was not significant. However, the
validation and combined groups (Table 24), 40 pound weight (Table 26),
and female sex (Table 27) demonstrated differences; and therefore,
presented a strong case for studying the AD interaction in factor IV.
The results of these analyses are the same as factor V: most of the
variance were explained by females lifting the 40 pound weight. The
results can be seen below:

Simple effect	MS(p)
A at d_1	.62
A at d_2	.29
A at d_3	17.26(.01)
D at a_1	12.84(.01)
D at a_2	.04

A "% variance of total interaction" column was shown in Table 31,
32 and 33 to describe the amount of variance explained within an inter-
action by the sum of squares of its components. For example, Table 27
shows that B at a_1 (female), B at a_2 (male) and total sum of squares
are, respectively, 415.8, 455.9 and 871.7. In Table 32, factor V's AB
interaction is depicted as having the following percentages of variance:

TABLE 30

TUKEY MEAN COMPARISON A POSTERIORI TESTS FOR DIFFERENCES
BETWEEN ACCELERATION PATTERNS OVER TIME
(B TREATMENT, ALL FACTORS)

FACTOR	MEANS OVER TIME					COMPARISON TESTS (prob)*				Explained Variance of Time With Acceleration
	1	2	3	4	5	1/2	2/3	3/4	4/5	
I	.75	1.35	-.47	-1.41	-.23	25.53	77.43	39.99	50.02	89%
II	1.25	-.53	-1.33	.33	.29	51.74	23.26(.01)	48.25	1.16**	74%
III	.05	+.18	-0.06	-.04	-.03	4.40	8.12	.68**	.34**	4%
IV	0.0	-.20	.02	-.01	.05	6.64	7.08	.94**	2.15**	3%
V	1.25	.33	-1.12	-.67	.25	28.23	46.01	14.28	29.20	75%

* (.01 = 4.40; .025 = 4.14)

** (NS)

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TABLE 31

TUKEY MEAN COMPARISON A POSTERIORI TESTS FOR DIFFERENCES BETWEEN ACCELERATION

PATTERNS OF SIGNIFICANT TIME/WEIGHT SIMPLE EFFECTS

(BD INTERACTION, FACTORS I, IV, V)

SIGNIFICANT SIMPLE EFFECTS	MEANS OVER WEIGHT			COMPARISON TESTS (prob)*			% VARIANCE TOTAL INTERACTION		
	$10(D_1)$	$25(D_2)$	$40(D_3)$	10/25	10/40	25/40	D_1B**	D_2B**	D_3B**
FACTOR-I TIME-4	-1.49	-1.43	-1.30	1.64	4.71(.01)	3.07	36.7	33.3	30.0
IV 2	-.09	-.02	-.50	1.35	7.84(.01)	9.19(.01)	4.6	1.9	93.5
V 1	1.37	1.31	1.06	1.13	5.70(.01)	4.49(.01)	35.0	31.7	33.3
V 2	.20	.36	.46	2.86	4.77(.01)	1.90	-	-	-
V 4	-.54	-.56	-.94	.23	7.28(.01)	7.06(.01)	-	-	-

* (.01 = 4.12; .033 = 3.65)

** (Tests Within Weight: All results same as TABLE 30 except -

FACTOR IV, 10 and 25 lbs, no differences over Time comparisons

FACTOR V, 40 lbs, Time 3/4, no difference)

TABLE 32

TUKEY MEAN COMPARISON A POSTERIORI TESTS FOR DIFFERENCES BETWEEN ACCELERATION

PATTERNS OF SIGNIFICANT SEX/TIME AND SEX/WEIGHT SIMPLE EFFECTS

(AB AND AD INTERACTIONS, FACTORS II, IV, V)

SIGNIFICANT SIMPLE EFFECTS	MEANS BY SEX		COMPARISON TESTS (prob)*	% VARIANCE TOTAL INTERACTION	
	Female(A_1)	Male (A_2)	Female/Male	$\underline{A_1B}$***	$\underline{A_2B}$***
AB INTERACTION:					
FACTOR-II, TIME-1	1.16	1.33	3.42(.05)	42	58
II 3	-1.22	-1.44	4.27(.01)	-	-
IV 2	-.33	-.07	6.03(.01)	92	8
V 2	.15	.53	8.47(.01)	48	52
				$\underline{A_1D}$**	$\underline{A_2D}$**
AD INTERACTION:					
FACTOR-V 10 lbs.	-.01	.04	-	99	1
25 lbs.	.07	.04	-	-	-
40 lbs.	-.15	.03	5.13(.01)	-	-

* (.01 = 3.64; .05 = 2.77)

** (Test Within Sex: Female - 10/25, 2.18, NS; 10/40, 4.13, .01 ; 25/40, 6.29, .01)

(.01 = 4.12, .033 = 3.65; Males - No Differences)

*** (Test Within Sex: All results same as TABLE 30 except male, Factor IV, no differences)

TABLE 33

TUKEY MEAN COMPARISON A POSTERIORI TESTS FOR DIFFERENCES BETWEEN ACCELERATION PATTERNS OF SIGNIFICANT TIME/MEASURE/PROGRAM SIMPLE EFFECTS

(BCE INTERACTION, FACTORS II, V)

SIGNIFICANT SIMPLE EFFECTS	MEANS BY MEASURE/PROGRAM				COMPARISON TESTS (prob)*					% VARIANCE TOTAL INTERACTION	
FACTOR-II TIME	E_1C_1 PRE/ CONTROL	E_2C_1 POST/ CONTROL	E_1C_2 PRE/ TRAIN	E_2C_2 POST/ TRAIN	E_1C_1 E_2C_1	E_1C_1 E_1C_2	E_2C_2 E_1C_2	E_2C_2 E_2C_1	E_2C_2 (train) /rest(untrn)	E_2C_2 B**	Rest**
2	-.44	-.42	-.42	-.85	.26	.23	6.04(.01)	6.00(.01)	5.13(.01)	34	66
II 3	-1.11	-1.22	-1.38	-1.61	1.50	3.78	5.50(.01)	3.22(NS)	4.52(.01)	-	-
II 2/3	-.78	-.82	-.90	-1.23	.88	2.51	8.16(.01)	6.52(.01)	6.79(.01)	-	-
V 3	-1.16	-1.10	-.96	-1.35	.92	3.13	3.96	6.16(.01)	3.64	32	68
V 4	-.64	-.61	-.53	-.95	.45	1.58	5.38(.01)	6.50(.01)	4.67(.01)	-	-
V 3/4	-.90	-.86	-.74	-1.15	.97	3.33	6.60(.01)	8.96(.01)	5.88(.01)	-	-

* (.01 = 4.40; .025 = 4.14)

** (Tests Within Group - All results for Time comparisons same as TABLE 30)

48% (female) and 52% (male). This column was mainly presented in these tables for descriptive purposes.

The tests of BCE interaction are contained in Table 33. The following four comparisons were conducted, as shown in the table, in order to evaluate training program effectiveness:

E_1C_1/E_2C_1 - pre/post untrained, should be insignificant

E_1C_1/E_1C_2 - pre of untrained/trained, should be insignificant

E_2C_2/E_2C_1 - post of untrained/trained, should be significant

E_2C_2/E_1C_2 - pre/post trained, should be significant

Time 2, factor II (.26 - .50 second) and time 4, factor V (.76 - 1.00 second) fulfilled these criteria. Interval 3 (.51 - .75 second) in both factors only partially met the requirements. However, when these data were combined with the other two time frames, the results were significant. These results indicated that training caused higher decelerations in the y axis of both lifts. This finding would appear to indicate that trained individuals demonstrated more efficient and coordinated lifts because they accomplished the same task with less effort.

Another area of interest was the investigation of the AD interaction in the knuckle-shoulder lift. The statement that "females lifting 40 pounds explained most of the variance in the y axis" left a question unanswered. Is this statement true for trained females? series of Tukey mean comparisons were performed using .01 as the level of significance for trained/untrained female lifters over the three weights. Using q = 4.76 to compare the 10/25, 25/40 and 10/40 pound lifts for factors IV and V, the following are the results of these tests:

	10/25	25/40	10/40
Factor IV			
Trained	.77	.75	.03
Untrained	2.34	4.78*	5.89*
Factor V			
Trained	.86	2.90	3.76
Untrained	1.96	8.81*	6.85*

These results indicate that most of the variance in the y axis for the sex/weight interaction can be attributed to untrained females lifting 40 pounds in the knuckle-shoulder lift. Differences were not noted for untrained/trained males and trained females. This statement would seem to emphasize the need for female training programs if women are expected to lift loads approximating 40 pounds.

t-Test Comparisons

Finkelman et al (1977) recommended that post-comparison analyses of the independent variables on each of the dependent measures should be limited to only those sources of variance found significant. The next series of tests, therefore, will study the following topics which were determined as being statistically significant from the ANOVA investigations:

(1) male/female movements in y axis during time intervals 1 and 3 of the floor-knuckle lift (factor II).

(2) sex differences in y axis during time period 2 in the knuckle-shoulder lift (factors IV and V).

(3) y axis decelerations of trained/untrained individuals during time intervals 2 and 3 (factor II) and 3 and 4 (factor V) for the floor-knuckle and knuckle-shoulder lifts, respectively.

The dependent variables studied will be limited to those items having a factor loading greater than .70. The t-test was used to compare the male/female and untrained/trained means on each of the segment accelerations. These analyses are contained in Tables 34 and 35. The level of significance was found by dividing .01 ("alpha" during Tukey tests) with the number of comparisons. The value .001 was judged to be the best approximate "alpha" after considering all of the tests that had to be conducted. As mentioned previously, the probability has been varied with the number of observations in order to minimize the occurrence of a Type I error.

As an aid in interpretation, stick diagrams of the average movements of the trained/untrained and male/female lifters in the floor-knuckle and knuckle-shoulder regimes are depicted in figures 4 to 7.

The broken line in these drawings signifies either the female or untrained person. When both lines overlap, the solid line represents both conditions or sexes.

Trained individuals had higher decelerations in the floor-knuckle lift (Table 34) during time frames 2 and 3 (.26 - .75 second) due to an initial position of bent knees and lower hip. As can be seen in figure 4, the knees and hip do the initial work, causing a domino-like effect in the other segments. The result was a more efficient lift with the initial thrust of legs/trunk causing the load to come closer to the body more quickly.

The male lift in the floor-knuckle regime (Figure 5) resembled the trained individual more than the female. Significant upward accelerations for trunk/arms (time interval 1) and decelerations for arms/hands (time interval 3) can be seen in Table 34. These observations can mainly be attributed to an initial position of lowered hip and bent knees. Higher initial movements of these segments caused higher decelerations later at the hands. Females initially relied more on back motion with straight knees. Male and female differences could possibly be explained by men being accustomed, even though inexperienced, to handling weight and physically using their body more than females.

During the knuckle-shoulder lift, the trained individual (Table 35) demonstrated more deceleration at the lower arms (.51 - .75 second) and lower arms/hands (.76 - 1.00 second). By visual inspection of Figure 5, these decelerations appear to be directly related to smaller trunk movement. Again, the trained person demonstrated a more efficient lift by moving the elbows/arms backward in order to keep the load as close to the body as possible. The untrained person relied more on the back movement to lift the weight as well as to maintain balance with the weight extended at the hands.

Males demonstrated higher upward accelerations at the lower arms/hands and lower movements at the upper arms/legs than females during time frame 2 of the knuckle-shoulder lift (Table 35). The time frame of .26 - .50 second was the period of highest decelerations (downward

TABLE 34

t-TEST COMPARISONS OF DEPENDENT VARIABLES FOR THE SIGNIFICANT INDEPENDENT
VARIABLE INTERACTIONS WITHIN THE FLOOR-KNUCKLE LIFT

Dependent Variable (factor loadings)	Factor II Data for Time Intervals 1/3				
	Males		Females		
	M	SD	M	SD	t-value
Time 1					
UL – Y (.84)	34.4	38.1	25.6	28.3	1.82
TR – Y (.95)	231.7	55.5	201.2	51.6	3.94*
Arm – Y (.85)	505.4	46.6	479.7	56.2	3.45*
Hand – Y (.77)	534.0	44.4	524.9	55.4	1.26
Time 3					
UL – Y	-58.9	48.6	-51.2	47.1	1.11
TR – Y	-335.4	104.1	-301.5	89.6	2.42
Arm – Y	-551.1	139.5	-473.8	133.8	3.92*
Hand – Y	-387.0	149.3	-305.3	170.0	3.54*

Dependent Variable (factor loadings)	Factor II Data for Time Intervals 2/3				
	Trained		Untrained		
	M	SD	M	SD	t-value
Time 2					
UL – Y (.84)	-85.6	41.2	-27.9	31.6	8.87*
TR – Y (.95)	-127.8	42.6	-56.1	76.8	8.08*
Arm – Y (.85)	42.5	105.5	78.1	180.3	1.66
Hand – Y (.77)	214.5	92.5	234.8	212.5	.92
Time 3					
UL – Y	-79.7	33.1	-47.1	52.8	5.02*
TR – Y	-375.8	51.8	-299.4	111.9	6.39*
Arm – Y	-585.8	126.2	-487.9	140.2	4.52*
Hand – Y	-431.1	116.4	-317.9	174.0	3.61*

* (t .001 = 3.30)

TABLE 35

t-TEST COMPARISONS OF DEPENDENT VARIABLES FOR THE SIGNIFICANT INDEPENDENT
VARIABLE INTERACTIONS WITHIN THE KNUCKLE-SHOULDER LIFT

Dependent Variable (factor loadings)	Factor IV/V Data for Time Interval 2				
	Males		Females		
	M	SD	M	SD	t-value
Time 2					
Leg – Y (.75)	-.1	.6	7.0	.8	46.94*
TR – Y (.93)	-4.3	5.6	-6.6	4.4	3.16
UA – Y (.80)	-12.7	16.4	-33.8	13.6	9.70*
LA – Y (.89)	12.7	42.9	-22.8	33.7	6.38*
Hand – Y (.90)	64.6	93.9	2.8	74.5	5.05*

Dependent Variable (factor loadings)	Factor V Data for Time Intervals 3/4				
	Trained		Untrained		
	M	SD	M	SD	t-value
Time 3					
LA – Y (.89)	-144.0	55.9	-100.1	32.3	5.16*
Hand – Y (.90)	-214.0	100.3	-239.1	88.4	1.55
Time 4					
LA – Y	-102.9	22.9	-57.5	24.0	11.75*
Hand – Y	-171.6	38.0	-140.2	47.2	4.65*

* (t .001 = 3.30)

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Figure 4: Stick diagram comparison of trained (solid line) and untrained (broken line) lifters in floor-knuckle regime.

Shoulder

Elbow

Wrist

Load

Hip

Knee

Ankle

Time: O (start)

.25 secs.

.50 secs.
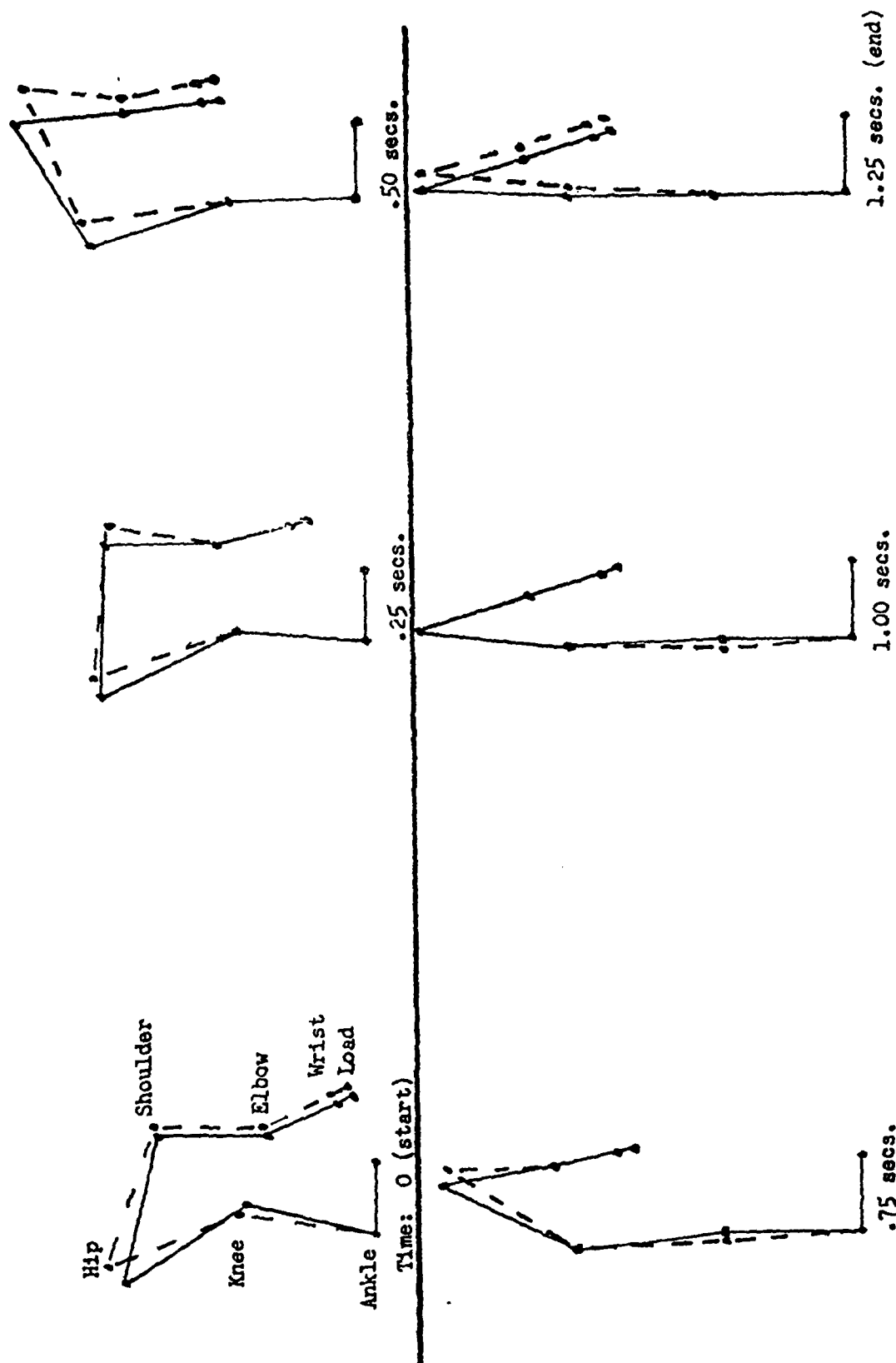
.75 secs.

1.00 secs.

1.25 secs. (end)
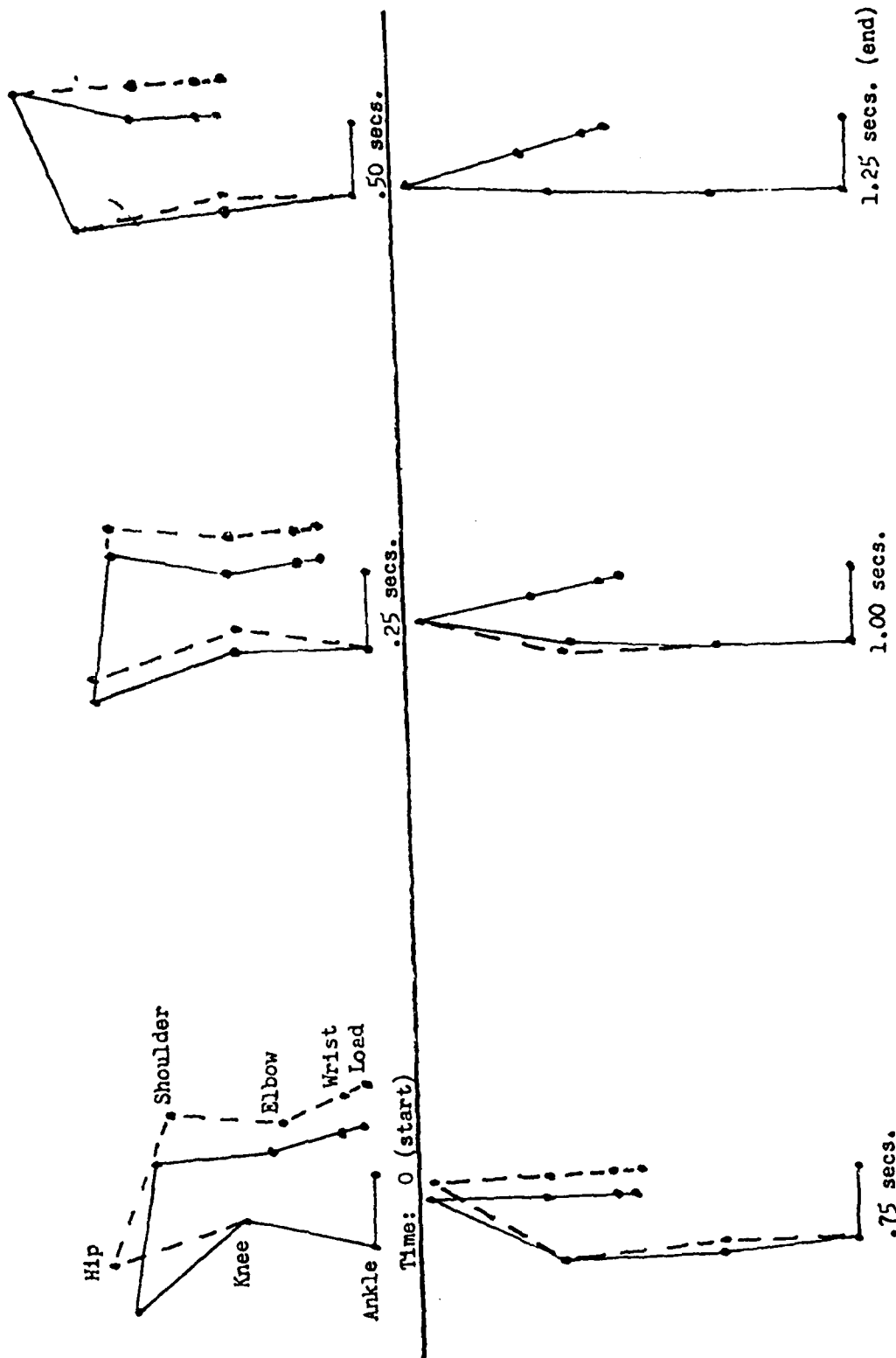
Figure 5: Stick diagram comparison of male (solid line) and female (broken line) lifters in floor-knuckle region.
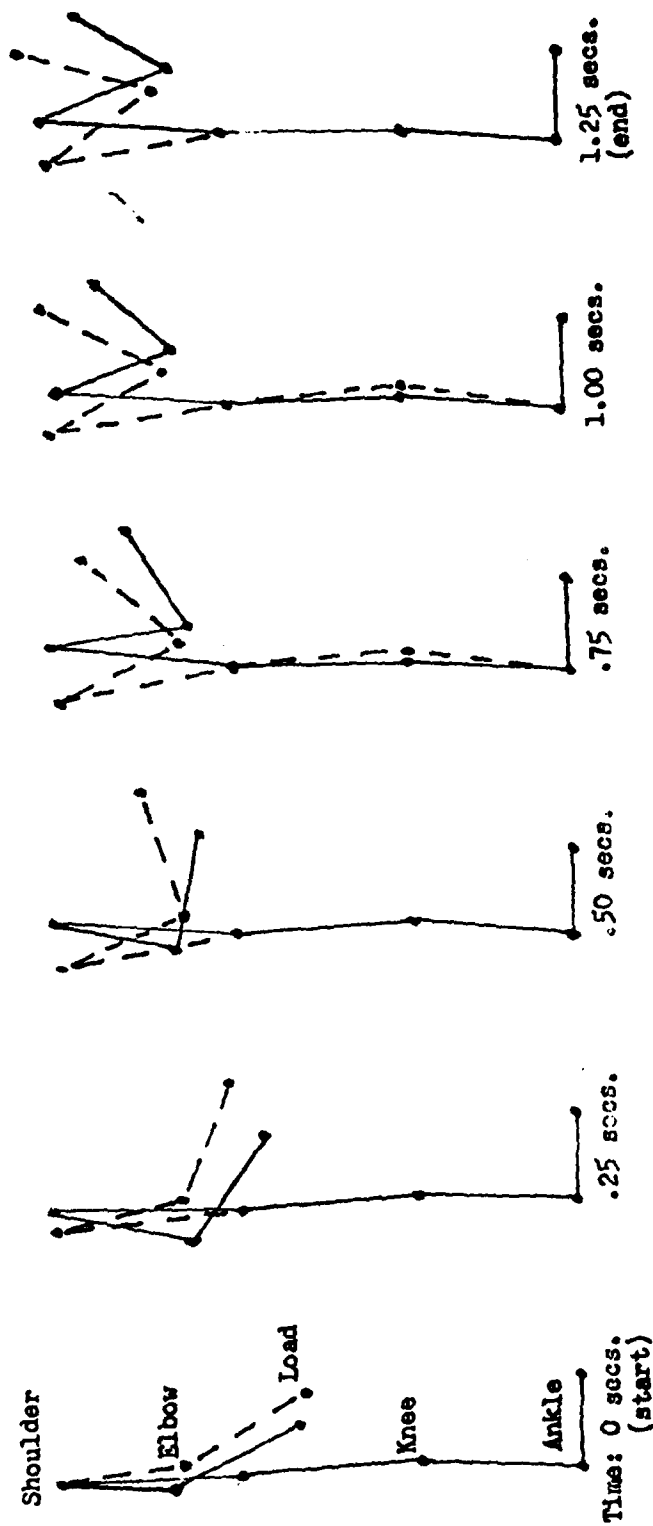
Figure 6: Stick diagram comparison of trained (solid line) and untrained (broken line) lifters in knuckle-shoulder regime.
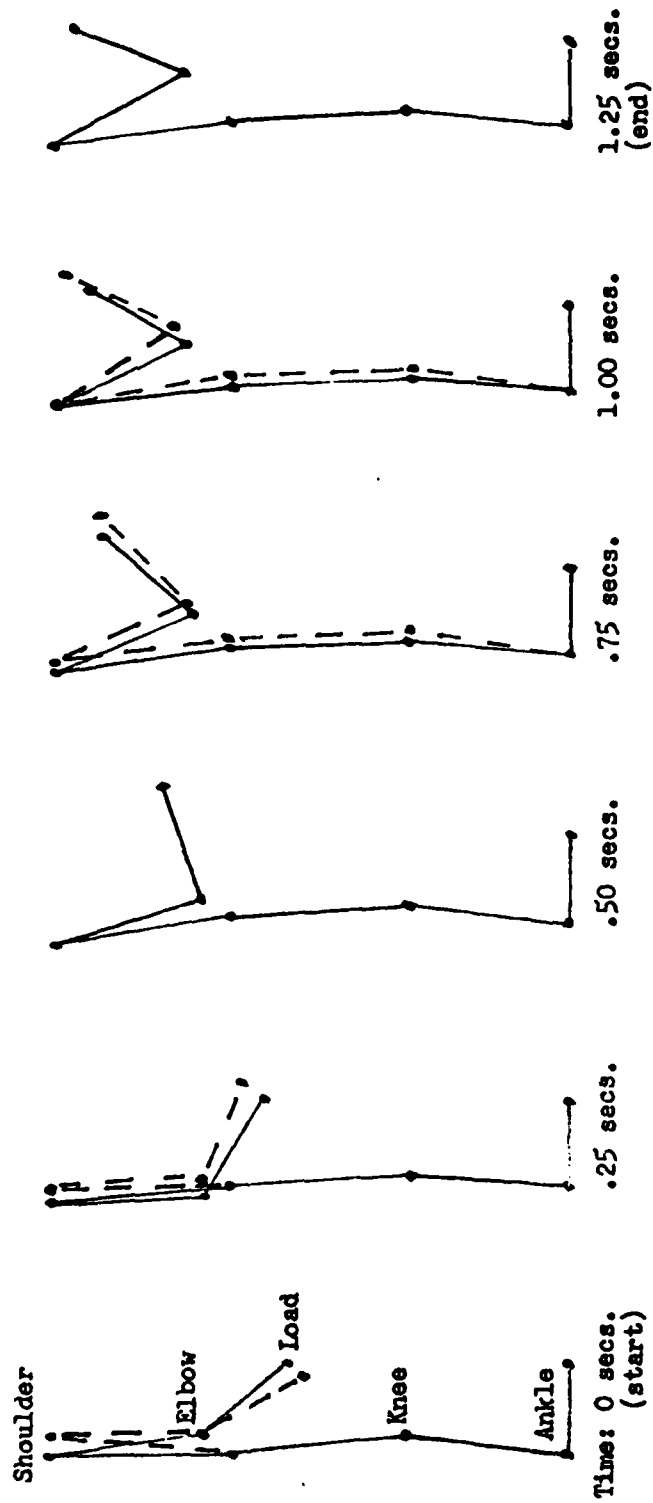
Figure 7: Stick diagram comparison of male (solid line) and female (broken line) lifters in knuckle-shoulder regime.

movement) of the trunk/upper arms for both sexes with the females being
higher. This point indicated that both sexes were coordinating their
movements during the most stressful part of the lift (passing weight
through horizontal). Through segment deceleration, upward motion at
the hands was helped, (Plagenhoef, 1971). In general, males appeared
to rely more on back and arm muscles while females used more leg and
downward back motion to compensate for strength differences. These
observations, which can be seen in Figure 7, demonstrated that females
and the untrained condition as well as males and trained people were
comparable.

The remaining part of this section will discuss the significant
results pertaining to electromyograms (EMG), platform forces and
inertial forces (at the hands). Since many authors have primarily
studied EMG and platform information, it was felt that this data too
should not be overlooked. Although these variables did not contribute
heavily to the factor-variable structure, they did have significant
loadings. From Tables 19 and 20, the variables with loadings of .20
and above are presented below:

	I	II	III	IV	V
Quadriceps	.20	-	-	-	-
Deltoid	-	-	.20	-	-
Sagittal	-.34	-.22	.21	-	.2'?
Coronal	.29	-	-	.22	.28
Transverse	.78	-	.22	-	.53

From this information, quadriceps and deltoid muscles loaded, respec-
tively, on the x axis of the floor-knuckle and knuckle-shoulder lifts.
This was as expected from the literature (Shinno, 1968; Hobart and
Vorro, 1974) since these lifts coincided closely with each muscle's
specific function. Transverse force explained most of the variance of
the platform variables within the factor structure. This too was
expected because of its importance in previous experiments (Ismail, 1968;
Perkins et al, 1974). The significant loadings of frontal force, al-
though lower than transverse, had also been previously identified. How-
ever, coronal force demonstrated a pattern which was observed in the

correlational matrices of Tables 9 and 10, and from the factor loadings. This was not reported by Perkins and Konz (1974), who found no apparent pattern.

Stepwise regression was also performed using EMG and platform variables as predictors and inertial forces at the hands as the criterion variables (Tables 17 - 20). The results were highly significant. This demonstrated some concurrent validity between the different sources of data collection and analysis.

Table 36 depicts the average force and strain data over time for both lifts. Table 37 contains t-test comparisons using average peaks for the sex, condition and weight treatment levels. Some investigators (Perkins and Konz, 1974) have used peak forces from the platform in their studies of load handling because they considered these values to be related to stress and safety. Positive force values in Table 36 represented backward, right and downward vectors, while the reverse was true for negative information. Deltoid and quadriceps EMG's were only studied, respectively, in the knuckle-shoulder and floor-knuckle lifts because of a lack of common variance in the other two muscle-lift relationships. The level of significance selected for these t-test comparisons in Table 37 was .01. This value was determined from dividing .1, the initial treatment probability, by the number of observations.

From Table 36, peak values in the floor-knuckle regime occurred generally in the first .5 second of lift (the acceleration phase). The deltoid, sagittal plane and inertial force (x axis) followed the same pattern with peak strain/stress being observed in the first .5 second of the knuckle-shoulder lift. However, peak forces in the transverse plane and at the hands (y axis) occurred during deceleration (time interval 4). Maximum coronal force happened during the .75 - 1.00 interval (time 4) in both lifts, and may indicate a slight loss of lateral balance toward the end of motion. Also, initial height of lift significantly effected the amount of force shown in both axes with floor-knuckle values being higher than knuckle-shoulder data.

TABLE 36

AVERAGE FORCE (kg.) AND ELECTROMYOGRAM MEASUREMENTS BY TIME DURING FLOOR-KNUCKLE
AND KNUCKLE-SHOULDER (COMBINED GROUP) LIFTS

Variables	Means by Time					M	SD
	1	2	3	4	5		
Floor-Knuckle:							
Quadriceps	.36	.33	.25	.24	.19	.27	.22
Sagittal	-.58	-.38	2.59	1.27	.14	.61	2.92
Coronal	-.28	.10	-.62	-.74	-.14	-.34	1.11
Transverse	5.64	11.48	-4.68	-11.00	-5.84	-.88	11.20
F-X	4.31	7.59	-1.85	-6.91	0	.63	5.53
F-Y	6.11	2.98	-3.99	-.39	0	.94	4.18
Knuckle-Shoulder:							
Deltoid	.23	.25	.19	.18	.15	.20	.15
Sagittal	.55	1.30	-.61	-.27	-.09	.18	1.67
Coronal	.17	.07	-.09	-.35	-.19	-.08	.84
Transverse	3.17	2.60	-3.08	-3.29	-1.65	-.45	4.60
F-X	-.09	2.37	.56	-1.29	0	.31	2.05
F-Y	1.74	.65	-2.47	-1.75	0	-.37	2.09

TABLE 37

t-TEST COMPARISONS OF AVERAGE PEAK FORCES (kg.) AND ELECTROMYOGRAMS FOR SEX, PROGRAM AND WEIGHT VARIABLES IN BOTH LIFTS

Dependent Variables	Peak Time Interval	Sex			Program			Weight			t-values for		
		Male	Female	t-value	Train	Untrn	t-value	10 lbs (4.5 kg)	25 lbs (11.25 kg)	40 lbs (18.0 kg)	10/25	25/40	10/40
Floor-Knuckle:													
Quadriceps	1	.37	.36	.29	.42	.34	1.70	.29	.36	.44	1.64	1.80	3.85*
Sagittal	3	3.46	1.73	6.02*	5.77	1.53	6.95*	2.12	2.58	3.08	1.94	1.52	3.17*
Coronal	4	.81	.67	1.03	.71	.75	.33	.49	.72	1.00	1.42	1.56	3.09*
Transverse	2	13.70	9.27	5.92*	18.49	9.15	8.80*	12.27	11.13	11.07	1.25	.07	1.44
F - X	2	17.27	16.47	.76	16.47	17.00	.35	7.47	17.04	26.09	4.70*	3.81*	8.65*
F - Y	1	13.69	13.47	.17	14.29	13.33	.58	5.51	14.98	20.24	5.63*	3.28*	8.98*
Knuckle-Shoulder:													
Deltoid	2	.22	.28	3.46*	.28	.24	2.04	.12	.21	.42	4.84*	9.86*	14.63*
Sagittal	2	1.05	1.55	3.24*	.90	1.43	3.54*	.59	1.01	2.30	2.53	6.09*	8.76*
Coronal	4	.22	.49	4.65*	.16	.41	4.36*	.03	.28	.75	4.15*	5.93*	9.67*
Transverse	4	3.59	2.99	2.15	2.89	3.42	2.08	1.37	3.07	4.53	8.14*	1.53	9.27*
F - X	2	5.60	4.93	1.02	5.33	5.20	.16	2.00	5.09	8.73	4.10*	4.32*	8.16*
F - Y	3	6.00	4.98	1.51	6.07	5.29	1.08	2.67	5.33	8.49	3.08*	3.88*	7.37*

* (t .01 = 2.58)

Trained/untrained males and trained females in Table 37 demonstrated higher forces in the sagittal and transverse planes in the floor-knuckle (F-K) regime. All females and untrained males had higher values in the sagittal and coronal planes in the knuckle-shoulder (K-S) lift. These findings appear to support the results previously stated in this investigation that:

(1) trained females and all males produced more movement during the floor to knuckle lift.

(2) all females and untrained males relied more or leg and back movement in the knuckle-shoulder lift to supplement either strength or balance differences.

The effect of object weight (Table 37) in the floor-knuckle regime was small and only significant between the 10 and 40 pound lifts. On the other hand, weight had a greater influence during knuckle-shoulder observations with most weight comparisons being significant.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS
FOR FUTURE RESEARCH

This investigation attempted to expand upon the dynamic biomechanical model developed by El-Bassoussi (1974) for non-repetitive, short duration lifts in the sagittal plane. This model expansion entailed not only using acceleration patterns and inertial forces which were mathematically computed, but also the more precise electromyogram (EMG) and force platform data. The result was a biomechanical model based on clusters of motion in two ranges of lift. These factor-variables were then utilized to compare lifting by male/female and trained/untrained individuals over time, weight and regime. In addition, prediction equations were generated in order to determine inertial forces at the hands from both the mathematically generated data from film and the force platform/EMG information from the recorders.

Conclusions

The significant conclusions of this report are as follows:

1. A biomechanical model utilizing factor analysis was developed for non-repetitive, short duration tasks in the sagittal plane. The five-factor model for lifting in the floor-knuckle (F-K) and knuckle-shoulder (K-S) regimes was shown to have validity by demonstrating that there were similarities between both the correlational matrices and the factor structures of two uncorrelated samples.

2. Slote and Stone equations were used in the development of the present model by determining angular velocities and accelerations for each body segment. The application of these relationships in the present model depended upon demonstrating their validity. Validation procedures were performed in the following three ways:

   (a) Goodness-of-fit tests indicated that observed and predicted (Slote and Stone) angular displacement distributions were similar for all but one joint's motion. This deviation, ankle in the floor-knuckle lift, was not considered very serious to model validity because it only

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accounted for a total displacement of thirteen degrees.

(b) Goodness-of-fit tests were used to show that the resultant forces in the x and y planes from both the force platform (sagittal/ transverse planes) and film negatives (inertial force at the hands) were similarly distributed in both lift regimes.

(c) Regression equations demonstrated that there were significant relationships between inertial forces at the hands (film) and forces at the feet (force platform). These equations were cross-validated through the use of weights from one sample to calculate the results of the second sample. The major contributor in the four equations (x and y planes in both F-K and K-S lifts) was the force in the transverse plane.

3. The major movement predictors of x and y inertial forces at the hands were accelerations at the arms (F-K) and lower arms (K-S). These results were also cross-validated using the two group comparison methodology.

4. Movement patterns were curvilinear in both lifts with peak accelerations and decelerations occurring within (a) the 0 - .25 and .51 - .75 second intervals in the y axis, and (b) the .26 - .50 and either the .51 - .76 (K-S) or .76 - 1.00 (F-K) time frames in the x axis. Although maximum deceleration in the x axis of the knuckle-shoulder regime was observed during time frame 3, it was not significantly different from time interval 4. The highest electromyogram strain values in both lifts coincided with peak acceleration periods within the first .5 second of the lift. In addition, some of the peak forces or stresses occurred during the first one-half second of the floor-knuckle lift (x and y axes, inertial forces; and transverse plane) and knuckle-shoulder regime (sagittal plane; and x axis, inertial force). These findings are generally in agreement with Grieve (1974) and Perkins and Konz (1974).

5. Most of the variance, in the x and y axes of the floor-knuckle range and in the y axis at the lower arms/hands for the knuckle-shoulder lift, can be explained by the time treatment. These findings

are due mainly to motion in factors I, II and V approximating the
Slote and Stone (1963) curvilinear relationships.

6. Coordinated movement in the knuckle-shoulder lift was shown
when maximum deceleration of the trunk/upper arms (y axis, .26 - .50
second) coincided with acceleration at the lower arms/hands (y axis,
0 - .50 second). This point indicates that both sexes are coordinating
movement during the most stressful part of the lift (passing weight
through the horizontal). By decelerating one segment with downward
movement, upward movement at the hands is helped (Plagenhoef, 1971).

7. Males had higher accelerations (0 - .25 second) and decel-
erations (.51 - .75 second) in the y axis for the floor-knuckle lift.
Significant upward accelerations for trunk/arms and decelerations for
arms/hands segments of the male subject could be attributed to an
initial position of a lower hip and more deeply bent knees than the
female. Lower trunk accelerations were also supported by Kumer (1974)
when he observed that female back extension occurred later in the lift
than males. Lumbar vertebrae remained fixed until a specific safe
level was reached, and then extension of the spine was allowed to begin.

8. In the knuckle-shoulder lift, males demonstrated higher upward
accelerations at the lower arms/hands and lower movement at the upper
arms/legs than females during the .26 - .50 second time interval. This
would seem to indicate that the men relied more on back and arm muscles,
while the women used more leg and back motion to supplement strength
differences. Strength differences between the sexes are well supported
in the literature (Ayoub, 1978; Snook, 1978).

9. Trained individuals demonstrated more efficient and coordinated
lifts in the y axis of both lifts by having similar patterns of acceler-
ation with, but significantly higher deceleration patterns from, the
untrained condition. These deviations in deceleration were observed
during the .26 - .75 second of the floor-knuckle lift and the .51 - 1.00
second of the knuckle-shoulder lift. This would appear to indicate that
trained people accomplished the same task with less effort. The obvious
differences between the groups are that the trained sample had lower
hips and more bent knees in the floor-knuckle lift. This initial thrust

combined with "domino-like" and coordinated movements during the lift resulted in the weight coming closer to the body more quickly. During the knuckle-shoulder lift, the trained person demonstrated a more efficient lift by moving the elbows and arms backward in order to keep the load as close to the body as possible. Untrained individuals relied more on back movement to lift the load as well as to maintain balance with the weight extended at the hands. The literature supports this study's conclusions that training results in more efficiency, coordination and rhythm (Komarek, 1968; Waterland, 1968; Vorro and Hobart, 1974).

10. Male movements approximated the trained condition. This finding could possibly be explained by men being more accustomed to physical exercise and the handling of weight. The male desire for competition and skilled performance somewhat supports this contention and has previously been outlined in the research literature (Deaux et al, 1975; House, 1974).

11. The weight variable had greater influence during the knuckle-shoulder lift with most of the weight comparisons between forces being significant. On the other hand, the effect of object weight in the floor-knuckle regime was small and mainly only significant between 10 and 40 pounds.

12. Most of the variance in the y axis for the sex/weight inter-action (factors IV and V) can be attributed to untrained females lifting 40 pounds in the knuckle-shoulder lift. Acceleration pattern differences were not noted between weight conditions and all males or trained females. This statement would indicate that training programs are necessary in the industrial environment if women are expected to lift loads of approximately 40 pounds. Women presently are having significantly more injuries with lighter loads (1 - 35 lbs.) and demonstrating poorer handling techniques than men (Shannon, 1978). In addition, the recommended acceptable weight of lift for women in these two lift regimes is roughly 40 pounds for the twenty-fifth percentile (25%) of the female population (Ayoub, 1978). This limit can be improved, as demonstrated by the results in this study, through training,

13. The application of a multivariate approach to analysis of variance not only isolated specific areas for future analyses but prevented raising the alpha error, and losing power and data information (Finkelman, 1977). Analyses of this pooled information, using t-tests to explore the significant interactions, allowed the investigator to go deeply into the qualitative relationships behind the significant quantitative numbers. The use of various sources of data besides movement on film resulted in the investigator having other avenues for data comparison. In all, the statistical methodology should have resulted in a valid investigation.

Recommendations for Future Research

The methodology outlined in this paper was used to analyze non-repetitive, short duration lifts. The same procedural steps could again be performed in another experiment which would collect pre- and post-measures of movement and stress in males/females and untrained/trained individuals during repetitive lifts. Repetitive models have been developed at Texas Tech (McDaniel, 1972; Dryden, 1973; Knipfer, 1973; Ayoub, 1978) relating sex, strength and anthropometric characteristics to amount of weight lifted within specific lift regimes. The same psychophysical technique, which was applied in these research investigations, could again be used to study movement as measured by film and force platform analyses. Strain measurements can be attained by estimating metabolic energy expenditure rates. In general, the recommended experimental design would consist of:

(1) sex - male and female

(2) time - intervals during lift (possibly 5 periods)

(3) program - trained and untrained

(4) measure - pre- and post-training program

(5) phase - beginning and ending of session to determine differences in fatigue due to work.

Size, strength and weight lifted would have to be controlled in this study. The training program should strive to optimize bodily movements rather than to develop muscular strength. Factor analysis, regression

analysis and analysis of variance are the recommended statistical techniques. Dependent variables would consist of the three force patterns from the platform, segment accelerations and forces from photography, and oxygen consumption measurements. Independent variables would test differences in short duration over time within a lift (Time), long duration over time within a session (Phase), training (Measure/Program), and male and female (Sex).

Another possible investigation would be the study of the influence of body size upon lift technique. Stratification based on either height, weight or somato types can be performed. Their effects can then be studied using a similar methodology as the one outlined in this report.

Other possible avenues of future research can follow along the lines of the various arguments presented against women assuming male-oriented jobs. Some of these viewpoints may have validity, while others, of course, may be quite prejudiced. Strength, endurance, coordination, and menstrual cycle are valid issues, and therefore require further investigation. The effects of these topics may be further influenced by the attitudes of women, which could further broaden the gap between the sexes. In other words, relevant research of the sex variable may require a systems or multivariate approach using various physiological, environmental, motor, intellectual, sensory and psychological variables.

In closing, the following recommendations were presented by Hudgens and Billingsley (1978) in their review of the Human Factors literature concerning the sex variables:

1. Increase the research performed on the sex variable.

2. Avoid the practice of small ratio of females to males because it contributes to measurement error and often precludes analysis of the sex variable.

3. Valid research and analysis of the sex variable, even when no differences are found, should be reported.

4. Studies involving female subjects should, ideally, include information as well as possible control for menstrual cycle and oral contraception.

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APPENDIX

A. Acceleration Patterns of the Bodily Segments

B. Analysis of Force and Electromyogram Data

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APPENDIX A: ACCELERATION PATTERNS OF THE BODILY SEGMENTS

Angular displacements during both lifts were found by measuring the angles of each joint from photographic negatives collected during the experiment. Tables A-1 and A-2 contain the means of these angles over time by lift, sex and program. With this displacement information, computations of velocity, acceleration and force profiles were accomplished. Table A-3 depicts the acceleration means by segment, time and lift in the x and y axes. Figures A-1 through A-4 show the discrete data in Table A-3 in terms of continuous curves of segment motion. These Tables and Figures are listed on the following pages as:

TABLE A-1

JOINT ANGULAR DISPLACEMENTS IN DEGREES FOR THE FLOOR-KNUCKLE (COMBINED GROUP) LIFTS

Treatment Levels	Ankle by Time						Knee by Time						Hip by Time						Shoulder by Time					
	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
Floor-Knuckle:																								
Female	79	86	91	92	92	91	144	159	173	180	183	185	48	66	106	145	170	179	106	88	60	35	22	18
Male	77	84	90	90	90	90	132	149	165	174	179	181	45	64	105	150	172	180	102	88	58	33	22	18
Untrain	78	83	88	90	91	91	142	152	165	175	181	183	48	66	105	146	169	179	105	88	60	36	23	18
Train	77	90	98	94	91	90	128	159	182	183	182	182	44	63	108	152	175	182	101	88	53	28	20	17
All	78	85	91	91	91	91	138	154	169	177	181	183	47	65	106	148	171	180	104	88	60	34	22	18

TABLE A-2

JOINT ANGULAR DISPLACEMENTS IN DEGREES FOR THE KNUCKLE-SHOULDER (COMBINED GROUP) LIFT

Treatment Levels	Ankle by Time						Hip by Time						Shoulder by Time						Elbow by Time					
	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
Knuckle-Shoulder:																								
Female	90	90	89	88	88	89	177	181	190	192	192	190	3	1	9	16	22	24	150	116	91	70	56	47
Male	90	90	89	89	89	89	181	184	189	189	189	188	3	-1	7	15	19	21	159	124	91	68	56	52
Untrain	90	90	89	88	88	89	179	183	190	191	191	190	4	4	12	17	20	21	154	122	93	69	56	49
Train	90	90	89	89	89	89	180	183	189	190	189	188	-1	-11	-4	13	22	27	156	115	86	69	57	52
All	90	90	89	88	88	89	179	183	190	191	191	189	3	0	8	16	21	23	155	120	91	69	56	50

TABLE A-3

AVERAGE BODILY SEGMENT ACCELERATION PATTERNS BY TIME DURING FLOOR-KNUCKLE (F-K) AND KNUCKLE-SHOULDER (K-S) (COMBINED GROUP) LIFTS

F-K/K-S Variables	F-K Acceleration Means by Time (cm/sec^2)*							K-S Acceleration Means by Time (cm/sec^2)*						
	1	2	3	4	5	M	SD	1	2	3	4	5	M	SD
LL X/Leg X	27.00	16.76	-17.39	-27.54	0	-.23	23.71	3.37	5.99	-4.40	-4.11	0	.17	15.90
UL X/TR X	-25.90	-29.70	14.40	32.65	0	-1.71	29.83	16.34	18.86	-15.02	-2.58	0	3.52	41.40
TR X/UA X	-61.77	149.39	61.46	-51.89	0	19.44	93.52	46.01	19.60	-16.86	21.35	0	14.02	75.16
Arm X/LA X	157.31	570.98	-18.62	-437.16	0	54.50	337.57	21.42	78.78	12.98	-9.53	0	20.73	89.46
Hand X	325.20	678.46	-119.44	-611.47	0	54.55	444.55	-27.74	219.85	37.35	-111.06	0	23.68	150.77
LL Y/Leg Y	1.77	-6.60	-5.76	-.27	0	-2.17	6.44	-.55	3.48	3.54	.23	0	1.34	15.26
UL Y/TR Y	29.98	-42.32	-55.07	-4.34	0	-14.35	46.84	-3.60	-5.48	4.58	3.25	0	-.25	29.70
TR Y/UA Y	216.43	-74.03	-318.45	-62.05	0	-47.62	185.01	-2.00	-23.28	-15.11	-16.41	0	-11.36	41.27
Arm Y/LA Y	492.52	69.20	-512.42	-71.08	0	-4.36	339.93	64.58	-5.01	-111.09	-68.83	0	-24.07	79.39
Hand Y	529.48	229.75	-346.19	-9.99	0	80.61	318.09	189.42	33.71	-232.82	-148.01	0	-31.54	170.70

* (accelerations measured during time intervals 0 - .25, .26 - .50, .51 - .75, .76 - 1.00 and 1.01 - 1.25)

Figure A-1: Acceleration Patterns in X-direction at center of gravity for each link during floor-knuckle lift.
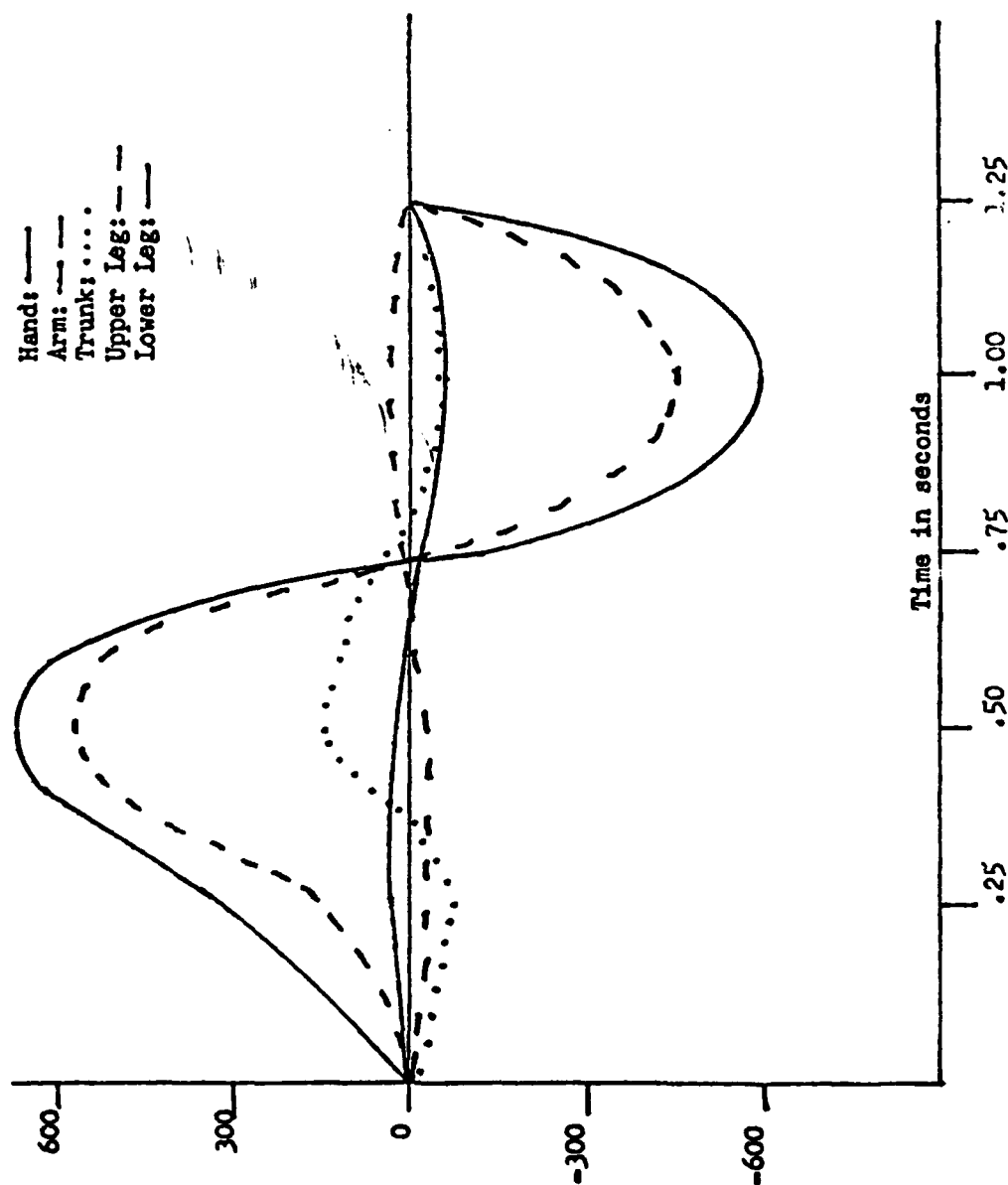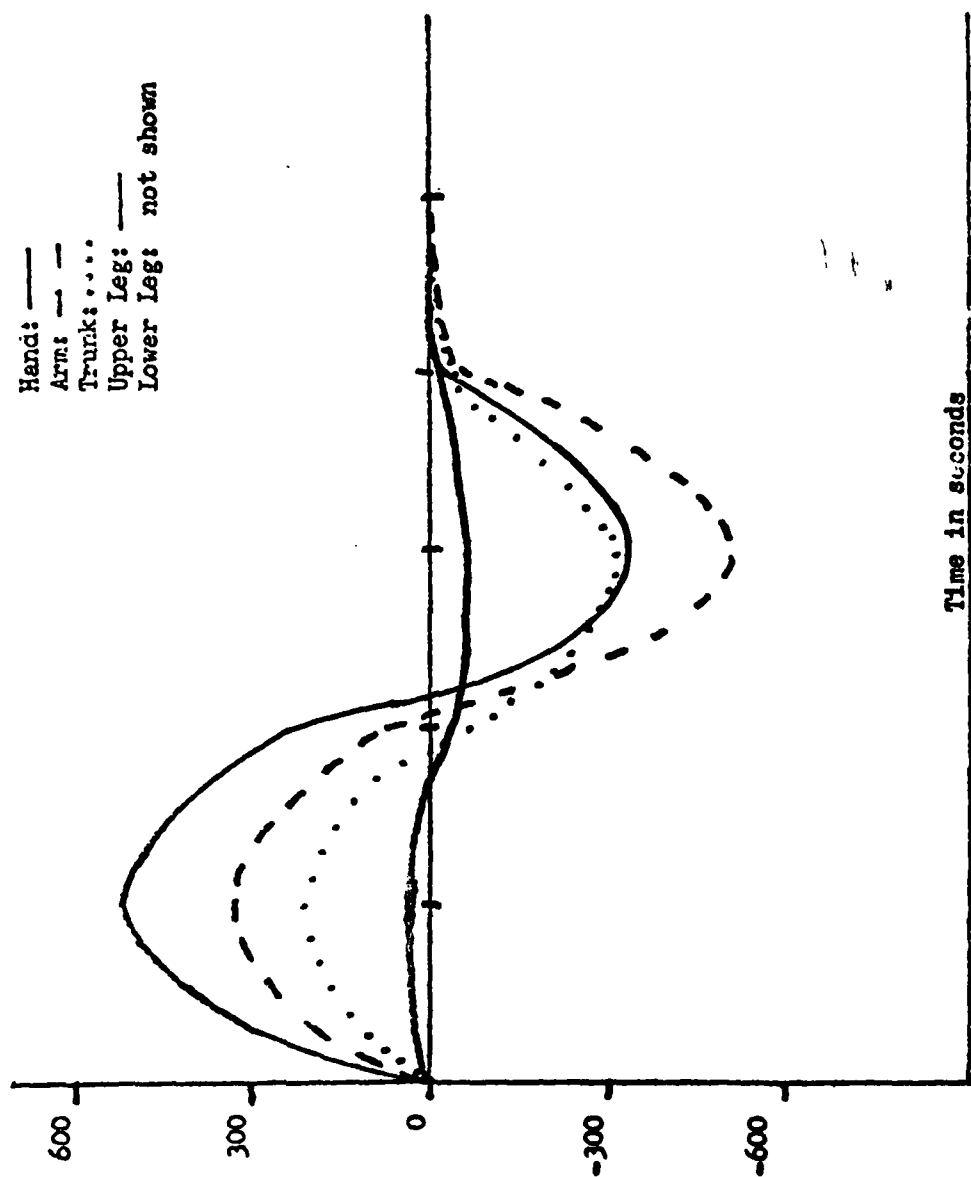
Figure A-2: Acceleration Patterns in Y-direction at center of gravity for each link during floor-knuckle lift.
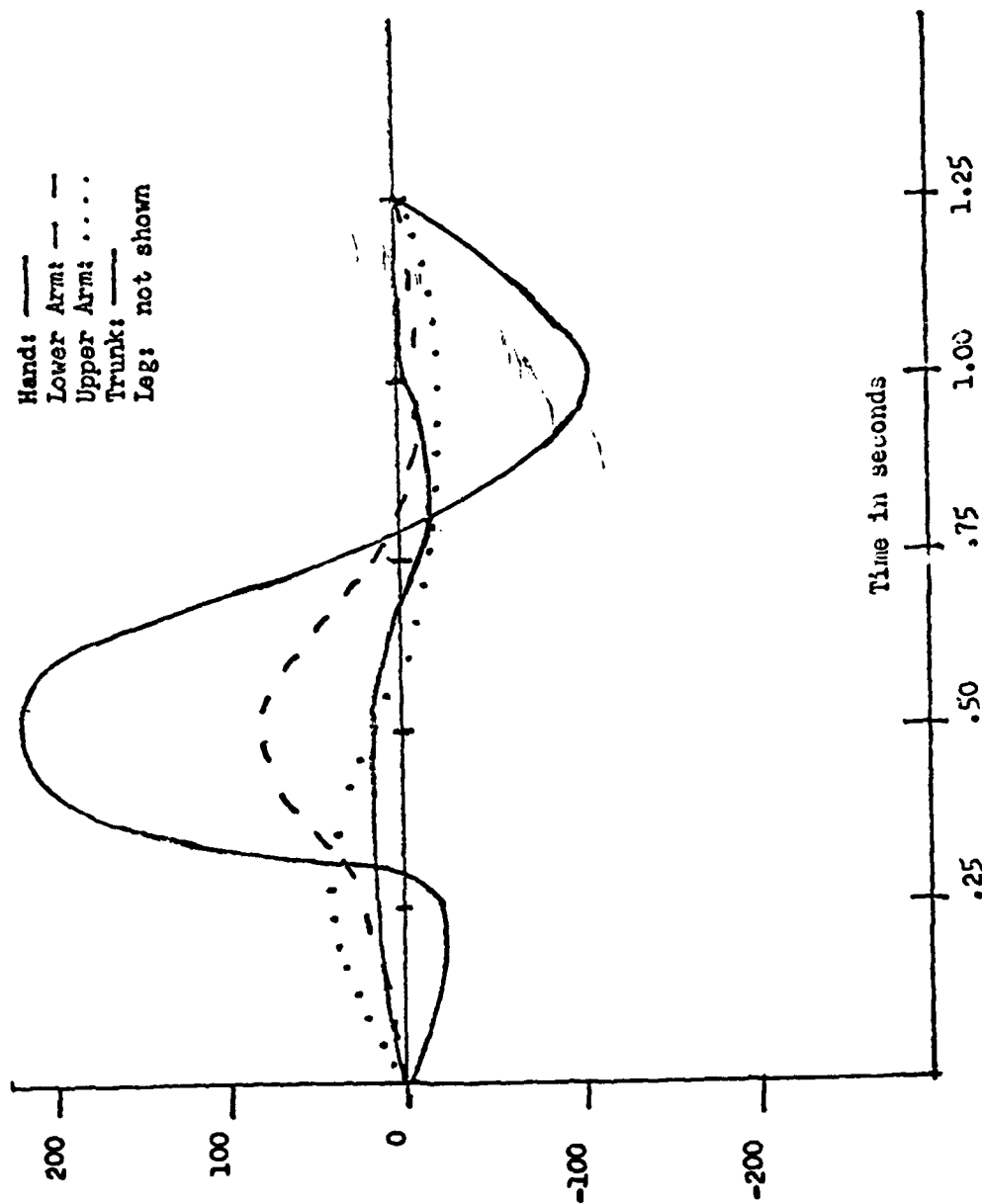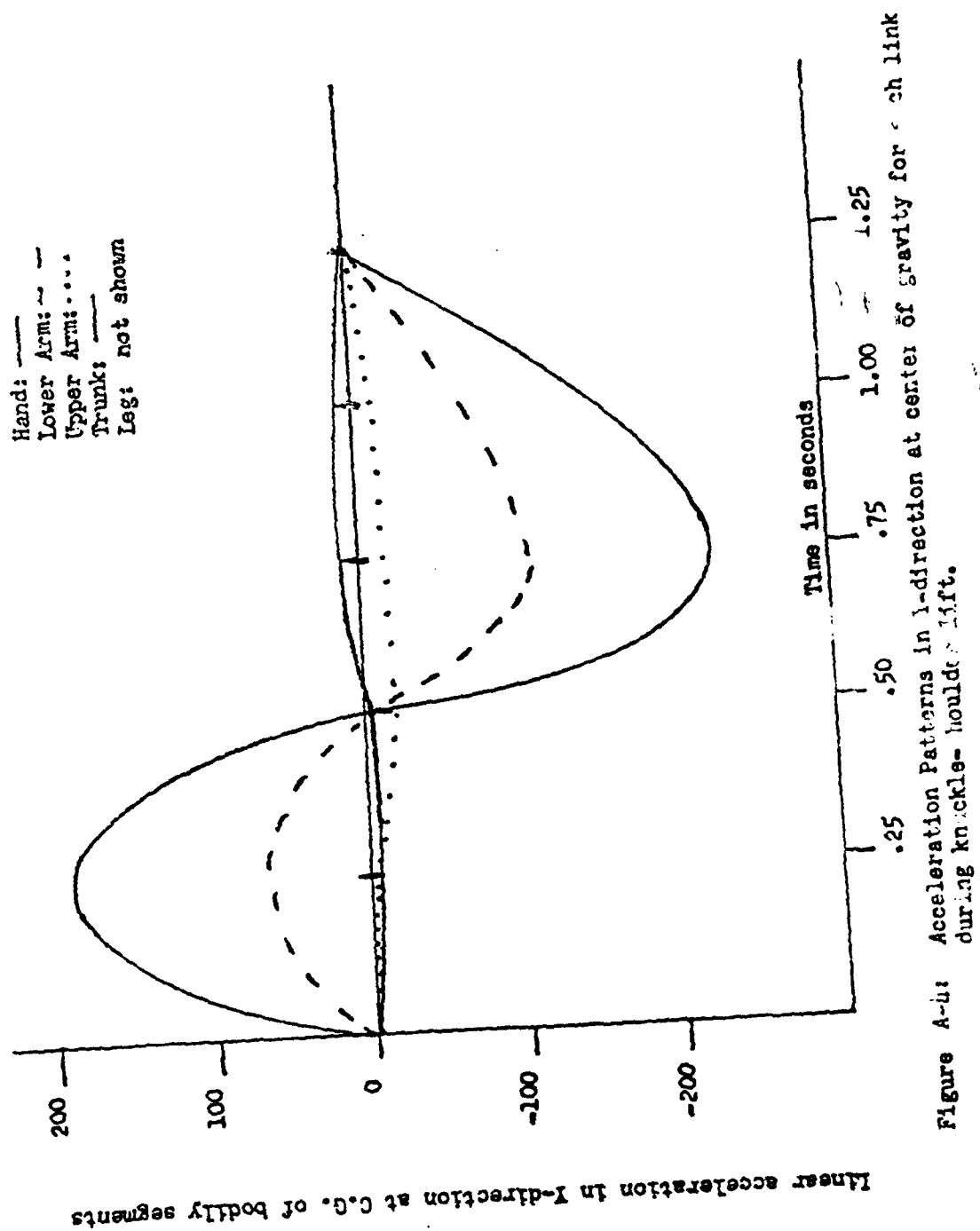
Figure A-3: Acceleration Patterns in X-direction at center of gravity for each link during knuckle-shoulder lift.

Figure A-4: Acceleration Patterns in X-direction at center of gravity for each link during knuckle-shoulder lift.

APPENDIX B: ANALYSIS OF FORCE AND ELECTROMYOGRAM DATA

Integrated electromyograms in arbitrary units were collected on two muscles (middle deltoid and rectus femoris, quadriceps) using the Sanborn integrating preamplifier. Two curves were determined - unstressed and stressed conditions. The unstressed muscular baselines were subtracted from the stressed muscular outputs in order to correct for measurement error. Due to the lack of common variance in either the x or y planes, the deltoid and quadriceps were not depicted, respectively, in the floor-knuckle and knuckle-shoulder portion: of the Tables in this Appendix section. A force platform was used to measure peak force (kg) changes at the feet in three reference planes - sagittal, coronal, transverse. Finally, inertial forces at the hands (kg) in the x and y axes were calculated from acceleration patterns at the hands. This information is shown on the following pages as average force and electromyogram measurements for the floor-knuckle and knuckle-shoulder (combined group) lifts by:

Time/weight . . . . Table B-1

Time/sex . . . . Table B-2

Time/program . . . . Table B-3

TABLE B-1

AVERAGE FORCE (kg.) AND ELECTROMYOGRAM MEASUREMENTS BY TIME/WEIGHT FOR THE FLOOR-KNUCKLE AND KNUCKLE-SHOULDER (COMBINED GROUP) LIFTS

Variables	10 Lbs. (4.5 kgs.) by Time					25 Lbs. (11.25 kgs.) by Time					40 Lbs. (18.0 kgs.) by Time				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Floor-Knuckle:															
Quad.	.29	.26	.19	.21	.14	.36	.28	.24	.23	.18	.44	.39	.31	.28	.26
Sag.	-.43	-.22	2.12	.99	-.18	-.65	-.38	2.58	1.19	-.04	-.66	-.55	3.08	1.64	.63
Cor.	.06	.19	-.60	-.49	.02	-.34	.36	-.64	-.72	-.13	-.56	-.25	-.63	-1.00	-.31
Trans.	9.67	12.27	-8.47	-10.04	-3.99	4.96	11.13	-4.79	-11.16	-5.97	2.30	11.07	-.80	-21.80	-7.55
F-X	1.66	3.36	-.67	-2.88	0	3.83	7.67	-1.15	-6.71	0	7.43	11.74	-3.73	-11.13	0
F-Y	2.48	.79	-1.22	.10	0	6.74	3.40	-4.38	-.55	0	9.11	4.75	-6.38	-.72	0
Knuckle-Shoulder:															
Del.	.10	.12	.10	.10	.09	.25	.21	.15	.15	.13	.34	.42	.32	.29	.23
Sag.	.53	.59	-.16	-.13	.13	.99	1.01	-.23	-.48	-.12	.44	2.30	-1.44	-.22	-.29
Cor.	.15	.02	-.07	-.03	-.03	.21	.22	-.24	-.28	.04	.15	-.03	.03	-.75	-.59
Trans.	2.35	.68	-2.68	-1.37	-.35	3.05	3.50	-3.12	-3.57	-1.00	3.30	3.63	-3.43	-4.53	-3.51
F-X	-.04	.90	.11	-.68	0	-.09	2.29	.31	-1.72	0	-.05	3.93	1.25	-1.48	0
F-Y	.66	.02	-1.20	-.50	0	2.10	.17	-2.40	-1.70	0	2.37	1.76	-3.82	-3.05	0

TABLE B-2

AVERAGE FORCE (kg.) AND ELECTROMYOGRAM MEASUREMENTS BY TIME/SEX FOR THE FLOOR-KNUCKLE AND KNUCKLE-SHOULDER (COMBINED GROUP) LIFTS

Variables	Female by Time					Male by Time				
	1	2	3	4	5	1	2	3	4	5
Floor-Knuckle:										
Quadriceps	.36	.34	.23	.22	.17	.37	.34	.26	.26	.22
Sagittal	-.80	-.86	1.73	1.35	.37	-.36	.10	3.46	1.20	-.10
Coronal	-.36	-.06	-.53	-.67	-.24	-.20	.26	-.71	-.81	-.04
Transverse	3.36	9.27	-2.46	-10.00	-6.13	7.93	13.70	-6.90	-12.00	-5.54
F-X	4.64	7.41	-2.40	-7.44	0	3.98	7.77	-1.30	-6.38	0
F-Y	6.06	3.69	-3.42	-.69	0	6.16	2.27	-4.56	-.09	0
Knuckle-Shoulder:										
Deltoid	.24	.28	.22	.20	.15	.22	.22	.16	.16	.15
Sagittal	.60	1.55	-1.22	-.21	-.05	.50	-1.05	-.01	-.34	-.13
Coronal	.16	-.01	-.02	-.49	-.23	.17	.15	-.17	-.22	-.16
Transverse	2.90	1.86	-2.84	-2.99	-1.55	3.44	3.34	-3.32	-3.59	-1.76
F-X	.15	2.22	.27	-1.06	0	-.53	2.52	.85	-1.52	0
F-Y	1.50	.47	-2.24	-1.52	0	1.92	.83	-2.70	-1.98	0

TABLE B-3

AVERAGE FORCE (kg.) AND ELECTROMYOGRAM MEASUREMENTS BY TIME/PROGRAM FOR THE
FLOOR-KNUCKLE AND KNUCKLE-SHOULDER (COMBINED GROUP) LIFTS

Variables	Trained by Time					Untrained by Time				
	1	2	3	4	5	1	2	3	4	5
Floor-Knuckle:										
Quadriceps	.42	.39	.24	.25	.24	.34	.32	.25	.24	.18
Sagittal	-2.84	-4.38	5.77	3.17	-.50	.18	.95	1.53	.64	.35
Coronal	-.53	.30	-.88	-.71	.03	-.20	.03	-.54	-.75	-.19
Transverse	5.66	18.49	-1.96	-14.29	-7.80	5.64	9.15	-5.59	-9.90	-5.18
F-X	3.10	7.41	-1.13	-6.79	0	4.71	7.65	-2.09	-6.95	0
F-Y	6.43	2.50	-5.22	-.16	0	6.00	3.11	-3.58	-.47	0
Knuckle-Shoulder:										
Deltoid	.25	.28	.16	.16	.15	.22	.24	.20	.19	.15
Sagittal	-.08	.90	.12	-.34	-.24	.77	1.43	-.86	-.25	-.04
Coronal	.43	.02	-.07	-.16	-.14	.08	.09	-.10	-.41	-.21
Transverse	3.95	2.76	-1.94	-2.89	-2.09	2.91	2.55	-3.46	-3.42	-1.50
F-X	.48	2.40	1.28	-.93	0	-.28	2.34	.32	-1.41	0
F-Y	1.97	1.10	-2.73	-2.20	0	1.62	.50	-2.38	-1.60	0